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MINERALS
IN WORLD AFFAIRS

By

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New York
PRENTICE-HALL, INC.

PRENTICE-HALL GEOLOGY SERIES

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First Printing.....June, 1943
Second Printing.....September, 1944
Third Printing.....August, 1947

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Preface

THE PART minerals have played in world affairs—their influence on social and economic conditions that breed wars and that affect decisions in these wars—may not be immediately apparent, but it is often real and profound.

Specialists have studied the role of minerals in many fields that bear on the past and future activities of man. With few exceptions, however, writers have confined themselves largely to a narrow and specialized approach. The difficulty of getting data in many cognate fields in which minerals play an important part, and the surprising way in which this information when assembled creates understanding of events that otherwise seem to have "just happened," led me to write this book. It is not a treatise but rather a survey of closely related fields. I have tried to collect sufficient material to satisfy the non-specialist who wishes information on mineral economics, geology, and trade in metals vital to industrial nations.

It has been necessary to speak boldly on some subjects on which I am not an authority, but in these cases information has been taken from sources agreed upon as good by competent specialists.

It is a pleasure to acknowledge the constructive criticism and material help of friends. Armand J. Eardley generously used his time to criticize and then transmute most of my rough sketches into finished pen-and-ink drawings. I am especially grateful for the many pertinent suggestions offered by W. B. Willcox, M. Oskar Fazekas, and Louis Hoskins, who read critically the chapters concerned with minerals and history, and to J. E. Wilson, who performed similar service on the rest of the manuscript. The statistical data that is the foundation of all conclusions concerning the relative position of industrial nations is taken from the *Minerals Yearbook*, from the *Foreign Minerals Quarterly* of the U. S. Bureau of Mines, and from the annual volumes of *Mineral Industry* published by the McGraw-Hill Book Company. Permission to use material from these sources is gratefully acknowledged.

Acknowledgment of help in the preparation of this material would indeed be incomplete if I failed to express gratitude to my brother, Major Harry D. Lovering, who generously made it financially possible for me to devote the time and to employ the secretarial and drafting assistance required to complete the manuscript. I cannot adequately acknowledge the help given me by Corinne Lovering in the preparation of this book; except for her protests, she would appear as co-author with me.

T. S. LOVERING

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Part I

ECONOMICS, HISTORY, AND GEOLOGY

CHAPTER 1

Background: Ethics, Minerals, and National Power

Methods of Investigation

WHETHER a man is a scientist, a philosopher, or a religious mystic, he seeks to discover truth. A scientist is at his best in the study of the physical world and its phenomena; a philosopher in the study of human nature and conduct; a mystic in the realm of ethics and the spirit. Each is concerned with making predictions, in formulating "laws" in his field; but their working methods may differ widely. The mystic depends on intuition or some higher power to inform him; his knowledge is not necessarily derived from reason —at least not from processes carried out in his conscious mind. Great truths are often achieved in this way. When a mystic states some deep conviction, he does it with such certainty of its truth that he feels no need of logic; nor does he feel that acceptance should wait until his prophecies are fulfilled. However, the depth of a man's convictions is no measure of their value. Other means of judging their worth are needed. A philosopher places his trust in reason rather than intuition, but he is content with a conclusion if no flaw can be found with the logic on which it is based. The scientist is often helped by intuition, but he depends chiefly on observation and reason. He hesitates to accept any so-called "laws" that are not based on experimental proof or its analogue, verifiable prediction. Unfortunately, the methods of science become increasingly difficult to apply as we depart farther and farther from the fields of physical science.

Human behavior is for many of us the least predictable phe-

nomenon in nature. When we endeavor to relate it to fields of science and philosophy, we find need to employ every method that promises to harvest a few additional grains of truth. Unfortunately, the ability to contribute is shackled to the limitations of background. Although the bias of the individual should always be remembered, it seems quite unfortunate that the value of the product of a writer is often prejudged according to the field of the reader. Many are willing to concede that philosophy overlaps the domains of both religion and natural science; but the relation of the latter two is not so clear. Many philosophers, such as Thomas Aquinas or our contemporary Rufus Jones, have much of the mystic in them; many scientists, such as P. W. Bridgman and A. S. Eddington, are in part philosopher; very few scientists are also outstanding mystics, but certainly George Washington Carver was both.

Scientist, mystic, and philosopher all have a deep concern for prophecy. For all three the ability to predict results accurately is a measure of success. For all three the only trustworthy foundation is deep understanding. Meditation and knowledge are the necessary precursors to understanding; either alone may be barren.

Whatever method is used to arrive at dependable conclusions, a broad knowledge of the elements entering a problem is essential. Our ability to appraise correctly is not helped by our prejudices; these constitute some of the obstacles most difficult to surmount along the dim trail that leads to understanding. Emotion and sentiment have a proper and indispensable role to play in our lives, but they will not serve as guides in our quest for truth.

The distinction between fact and inference should be recognized wherever possible; but this distinction is especially difficult for the student of social and political questions to make. Although a deliberate effort is made to present material objectively here, the reader is warned to be on guard against the unintentional subjectivity that may creep into a study of the part played by minerals in world affairs. Many of the factors vital to an understanding of social problems and of the course of international affairs are elucidated by economics, history, geography, and geology. With the interplay of these four branches of knowledge, the following pages are concerned.

National Survival Versus National Ethics

Survival is the primary concern of all nations, but the increase of national power, wealth, and culture is a related and nearly equal

motivating force. The means for gaining these ends have nearly always been governed by expediency. Ethical and philosophical considerations enter national policy in varying degrees. Few people would not condone their government's transgression of international law when their material interests were at stake. Self-interest as the primary motivation of nations may be decried or acclaimed; its reality should be recognized. For thousands of years the basic philosophy of nearly all those who have determined the course of history has been that of Machiavelli: *the end justifies the means*. The philosophically minded may say that during this time the results of that guiding principle have been recurring cycles of wars, accretionary growth, destructive competition, war, and exhaustion; but until some other outlook is reached, this is the concept with which we almost universally deal. A possible exception of great interest in recent years has been India under the leadership of Gandhi.

History is determined in large part by national policies, which in turn are directed to promote what are considered the best interests of those participating in the government. These interests center primarily in personal safety and comfort, public and private acclaim, acquisition of wealth, attainment of power, and the more generous impulses to raise the standard of living of friends, dependents, and members of the body politic.

The means chosen to attain these ends differ widely; they will conform with the mores of those on whom the government most depends, or the mores will be changed to accord with political policies by suitable means. This latter course is seldom difficult within a nation whose self-interest is served, but it may be impossible to persuade the people to a satisfactory viewpoint in a foreign country that has conflicting interests.

The right of the state to use propaganda and various coercive measures to further its interests has been recognized and employed by all governments. Where the "rights" and ethical views of the individual run counter to the means of securing national ends deemed desirable by a government, judgment is usually rendered against the individual. This difference between individual ideals and the right of the state to use a standard based on what seems expedient to achieve a justifiable end is clearly brought out in decisions of the United States Supreme Court. The issues are so well stated in the 8–to–1 decision in the "Flag Salute" case that the

excerpts that are given below should be studied thoughtfully:(7) *

> National unity is the basis of national security. (p. 1013)
>
> The precise issue, then, for us to decide is whether the legislatures of the various states, and the authorities in a thousand counties and school districts of this country are barred from determining the appropriateness of various means to evoke that unifying sentiment without which there can ultimately be no liberties civil or religious. . . . The influences which help toward a common feeling for the common country are manifold. Some may seem harsh, and others no doubt are foolish. Surely, however, the end is legitimate. (p. 1014)

Mr. Justice Stone dissenting:

> The law which is thus sustained . . . does more than suppress freedom of speech and more than prohibit the free exercise of religion, which concededly are forbidden by the First Amendment and are violations of the liberty guaranteed by the Fourteenth. For by this law the state seeks to coerce these children to express a sentiment which, as they interpret it, they do not entertain, and which violates their deepest religious convictions. It is not denied that such compulsion is a prohibited infringement of personal liberty, freedom of speech and religion guaranteed by the Bill of Rights, except insofar as it may be justified and supported as a proper exercise of the State's power over public education. . . . Government has a right to survive. . . . It may make war and raise armies. To that end it may compel citizens to give military service . . . and subject them to military training despite their religious objections. It may suppress religious practices dangerous to morals, and presumably those also which are inimical to public health, safety and good order. But it is a long step, and one which I am unable to take, to the position that government may, as a supposed educational measure and as a means of disciplining the young, compel public affirmations which violate their religious conscience. (p. 1016)
>
> History teaches us that there have been but few infringements of personal liberty by the state which have not been justified, as they are here, in the name of righteousness and the public good, and few which have not been directed, as they are now, at politically helpless minorities. (p. 1017)

Again, quoting a famous opinion of Justice Roberts:(8)

> But subject only to constitutional restraint the private right must yield to the public good. . . . And the guaranty of due process, as has often been held, demands only that the law shall not be unreasonably arbitrary, or capricious, and that the means selected shall have a real and substantial relation to the object sought to be obtained. (p. 249)

A nation commonly outlasts many governments. Each group as it comes to power feels free to rescind previous commitments that seem onerous, and, in turn, to bind the nation to a course of action extending beyond its term of office. The breaking of treaties, and other violations of international law, are the logical result. No one of the world powers has maintained a blameless record in this respect during even the past decade. Within the tenure of a single government, there is little hesitation to disregard agreements and law—statutory, international, or constitutional—if an emergency

* Numbers in parentheses denote references listed at the ends of chapters.

is thought to exist and if the national interest is believed to be best served by this disregard. The acts that spring from such disregard seem to require as justification only two statements: 1) Vital national interest is served. 2) Another (competing) nation has already violated international law in some respect, or is about to do so. Both statements usually seem to be true, and so long as they are accepted by the vast majority of the peoples of the world as a valid excuse for abrogating international law, so long must we anticipate that the promise of a statesman or a nation can be trusted only while it seems to the best interests of that nation to keep its word. This is regarded as a truism of paramount importance by absentee owners of valuable property in foreign countries; it will be discussed further in Chapter 2.

Man and Minerals

The concentrated value of gold, silver, and other minerals has stimulated exploration; their exploitation has led to commerce and power, their exhaustion to national decline and poverty. Mineral production has been instrumental in determining the course of history many times in the past and promises to be of increasing importance in the future. The aggregate area underlain by mineral deposits of economic importance is only an insignificant fraction of 1 per cent of the earth's surface, and the geographic position of the individual deposits is fixed by some accident of geology. Since no second crop may be expected, rich diverse mineral deposits are a nation's most valuable but ephemeral possession—its quick assets. Much of history has been made by men who have successively gained wealth and power in different countries through the liquidation of these assets. Because of their evanescent character, restricted occurrence, and indispensability to industry everywhere, the exploitation of mineral deposits engenders many unique problems in national and industrial economy. An understanding of the geology and economics of minerals and the geographic distribution of past and future sources of production will enable us better to interpret history and will prepare us for the political changes to come.

In the following pages attention will be given to: factors determining national power; economics of the mineral industries; the part played by minerals in history; the geology, geography, and control of important minerals and their normal trade movements

and volume; the influence of minerals in shaping recent events; and finally, the outlook for the future.

National Power

The chief factors by which we judge a nation's power and influence in world affairs include: territory held, amount of commerce and wealth, military strength, and the spirit of the people.

Territory

The part of the globe controlled by a nation determines its natural material resources and the character of its terrain. Topography will influence the routes followed by commerce to the benefit of some and the disadvantage of others; earth features have had a far-reaching influence in the rise and fall of nations. Resources, climate, topography, soil, and accessibility in large part determine the size of a population and its pursuits.

An advanced stage of culture or civilization has always depended on agricultural products, transportation, and manufacturing industries. A fertile country with a favorable climate is usually well populated. If fortunately situated with respect to cheap transportation routes, exchanges with areas less productive are almost inevitable, and growth in power is a natural consequence. The presence of other natural resources such as forests, game, mineral deposits, and waterways, each make certain contributions to the national economy and together add to the wealth and power of the nation controlling them.

No civilized nation has ever been self-sufficient in all the things it requires. Lack of self-sufficiency in any one region results inevitably in purchase, barter, or theft. As the outcome of war is uncertain and its cost may be high, the use of force is generally the expedient of a people with little to lose and much to gain. Because of the risk involved rather than of the moral questions raised, barter has been preferred to war. In a paper published by the United States Bureau of Mines in 1936, C. W. Wright(10) makes this significant statement:

> Wars are usually industrial and often fought to the point of utter exhaustion of one of the contestants. It is also a fact that an industrial power will go to war whenever economic pressure becomes too oppressive and when it is believed that war will win for them the control of sources of raw mineral supply and permit territorial expansion, they will do so regardless of any international treaties or agreements. Thus the question of mineral resources plays an important role in causing war and in case of war a nation's capacity to produce the

necessary mineral products may be a matter of life or death. Stocks of metals and minerals may be built up from outside sources and even during a war they may be supplied by an outside nation, but to be powerful from a military standpoint a modern nation should be able to produce most of the required minerals from domestic sources. With these facts in view one may understand more clearly the reasons for Germany's present activities in the development of and preparations to produce from mineral deposits which in normal times would be considered of no value.

Commerce and wealth

The wealth of a nation depends on its manufacturing industry, agriculture, mineral resources, and trade. For many decades the value of manufactures has far exceeded those of other sources of wealth in the more powerful nations. The amount of income depends on volume and a favorable ratio between the cost of production and selling price. Steady skilled labor, cheap power, cheap raw materials, and cheap transportation to centers of consumption combine to give the optimum conditions for a satisfactory cost ratio. The volume of the output depends on demand, which in turn is governed largely by the cheapness, quality, and efficiency of the products when put in use. Constant improvement is required for continued domination of markets; this means inventive genius, organizing skill, business acumen and engineering talent in the personnel.

Both power and raw materials are largely derived from mineral deposits, such as coal, petroleum, and iron. Minerals are thus the foundation of the modern manufacturing industry and the thews of transportation. They are also vital to agriculture, since mineral fertilizer is essential to the continued productivity of farm land. Agricultural output is dependent on climate, soil, geography, and people. It remains relatively fixed in kind, amount, and place, thus differing profoundly from mineral production. Agriculture has a further distinctive difference from the mineral industries: a needed agricultural commodity can be grown in suitable new areas whenever economic conditions make this desirable. Thus, deficiency in agricultural or sylvan commodities need not be permanent if the proper soil, climate, and workers are available. Deficiencies in minerals are permanent.

For thousands of years, trade has been an important source of wealth and power. The flow of goods from one part of the world to another entails a source of supply, a transportation route, and a market. Profit is required at all three places. Wealth has generally centered at the markets, to a less extent at strategic points

on the routes used, and to a still smaller extent at the source of raw material. The choice of possible routes between source and market is determined by the relative cost, speed, and safety of each. Cheap transportation has obvious advantages, but cheap slow freight may be less profitable than faster but more expensive transport. A saving in freight charges would also mean little, if damage or theft destroyed a substantial amount of the shipments. The policing of trade routes has always been of great importance to commerce. Great Britain is not the only nation that has depended on its ability to safeguard trade routes for its national livelihood. In ancient time the Assyrians protected the routes through their rugged country, but they taxed caravans heavily to support the armed forces that guaranteed a measure of security to those who followed roads along the Euphrates valley and through the mountains that wall the eastern Mediterranean Sea. Not only did such countries police commerce within their borders; they also engaged in never-ending wars with nations through which competing trade routes ran. The revenues that were the source of a nation's power changed in proportion as the popularity of one route diminished and that of another increased. Much of history centers around the struggle for control of trade routes between the East and the West.

Markets always tend to build up at intersections of trade routes as well as at their termini; both soon become centers of population which draw their sustenance from commerce. The interests of such cities or nations are apparent. Innovation in methods of transportation may prove as disastrous to them as war. When two systems are competing, the cost of moving freight over each will generally differ but little. If a large differential is possible, either the expensive route is abandoned or, as is more probable, the commerce moving over the cheaper route will be taxed to a point that will approach the cost of transportation of the second route. This situation is well illustrated by the decline of Bagdad in the tenth century and the concomitant rise of the countries of the Nile (see page 50). Before the Industrial Revolution, large cities were generally on waterways at the termini of trade routes in fertile agricultural regions. With increasing perfection of mechanical transportation, dependence on proximity to agricultural areas has diminished, and population centers move toward places that provide optimum conditions for successful manufacturing industries. The great centers of commerce will be found here or near by where several trade routes converge because of favorable geography.

Trade depends not only on available transportation routes but also on the exchange of desired commodities. If cleverly done, barter may be as advantageous to a country as the exchange of money for goods; the use of metal as a medium to facilitate exchange is only a special form of barter. Whether money or goods are exchanged, it is impossible for trade to continue long between two countries unless their products and deficiencies are directly or indirectly supplementary. It is quite possible to maintain satisfactory and mutually profitable trade among three or even more countries, none of whom make directly compensating exchanges of goods, if in the aggregate the carriers are able to transport as much out of each country as they bring in. The use of barter, however, in such a complex system leads to difficult problems. It has proved nearly impossible for private commercial enterprise to undertake barter except to a very limited degree; but where all industries are state controlled, this has been done with a certain measure of success. Germany, though nearly bankrupt of gold, managed to tie up several important sources of raw materials for many years with barter agreements. Such arrangements are least difficult to negotiate between countries that, because of a native supply of mutually complementary products, are natural economic units. Many such units exist in the world, and one of the difficult post-war problems will be to correlate satisfactorily those that have been disrupted by the war.

Military strength

The more obvious factors determining military strength include: armament, manpower, supplies, morale, and geography. The military power of a people is appraised by their success in conquests or their ability to resist aggression. Unless actually tested by war, military power can only be judged by the influence a country exerts in world affairs and its success in obtaining concessions from reluctant neighbors. A country may have military power entirely adequate for defense but lack the strength to force its will on competing countries. Since economic competition in its most intense form is war, world powers have all felt it necessary to be prepared to use force to protect their trade, their country, and their markets, and, if necessary, to destroy competitors whose commercial success might injure them or even spell their ruin. Smaller nations have in general depended on that first and most important line of defense, national policy, and have limited their armed forces to what was

required for policing their country and protecting it from attack.

The cost of outfitting and maintaining armed forces has always been relatively high. The size and maintenance cost of an army and navy adequate for defense would seem much less than that for offense, were it not for the fact that military leaders agree that battles can seldom be won by defensive measures alone. The military are expected to contribute either protection or national spoils when engaged in war, but during peace they make no direct contribution to the economy of a nation. Each soldier represents not only a burden on the community that must support him but also a real loss through his withdrawal from productive work and the necessity of using the labor of many others to provide his equipment. During the first world war, five men were required in industry to keep one man at the front; during the second world war, the number of workers needed to supply a soldier engaged in combat activity rose to fourteen.

The people who voluntarily give a substantial part of their earnings to a military machine regard it either as an investment or as insurance. The Roman army was an investment, and a very profitable one to its backers for a time; the United States army is regarded by the American people primarily as insurance. With few exceptions nations whose forces carry out successful military operations expect material recompense from those defeated. As an investment, however, the entries for war have been overwhelmingly in the red. The fruit of victory in the first world war was expensive. From 1914 to 1918 the immediate cost in dollars and dead is impressive. (See Table 1.)

TABLE 1

KILLED AND CASH COST OF FIRST WORLD WAR, 1914–1918, BASED ON FIGURES GIVEN IN WEBSTER'S NEW INTERNATIONAL DICTIONARY

Countries	*Cost*	*Dead*
Austria-Hungary	$20,623,000,000	911,000
British Empire	48,398,000,000	807,000
Bulgaria	815,000,000	101,000
France	25,813,000,000	1,428,000
Germany	40,150,000,000	1,611,000
Italy	12,414,000,000	507,000
Rumania	1,600,000,000	339,000
Russia	22,594,000,000	2,762,000
Turkey	1,430,000,000	437,000
United States	32,080,000,000	107,000
Other Entente powers	2,364,000,000	994,000
Total cost	$208,281,000,000	10,004,000

When the value of the property destroyed is added to the cash outlay, the total cost approximates 400,000,000,000 dollars. One out of five who went to that war never returned; a similar number required hospitalization, and 10 per cent came back seriously injured. For each man killed and injured in any war there may be several emotional or economic casualties among dependent noncombatants. The gains that accrue to the people of a victorious nation must, of course, be balanced against the losses suffered, both economic and emotional.

Most wars are primarily economic (see sections on history), but as there are many different economic interests within a nation, it follows that some will benefit more than others and that some will suffer disproportionately. In general, the manufacturing industries stand to make the most immediate gains, unless they are so situated that they risk physical destruction. Even in such a situation it was possible in the first world war for influential interests to secure a surprising degree of immunity, as in the case of M. de Wendel, whose Briey blast furnaces and steel works behind the German lines in northeastern France were officially forbidden the French as targets.

It is only natural that the manufacturer of military equipment should be treated with consideration during peace in order that his products, so essential to the prosecution of war, may be produced by a practiced personnel in a going concern when hostilities are started. The demand on a manufacturer of armament during war is far beyond that of the normal peace-time requirements of his country. If productive capacity is to be maintained, profitable markets for his goods are essential in the lean years of domestic peace. The logic seems inescapable that, unless completely subsidized, he must sell where war or active preparations for war are going on. Complete support by the government during both peace and war might well lead to government ownership, an end that would scarcely seem attractive to the armament manufacturers, though it might be best for the world community and for his own country as well. Lacking a subsidy, it is to be expected that munitions firms will seek business wherever they are permitted to go. Few of the military advocate government ownership; they believe that private manufacture of armament is less expensive and should be stimulated so that a large productive capacity will be available when needed. To this end, the war departments of most countries encourage the manufacture and export of munitions by private firms.

The vested interest that is given to private manufacturers of armament has been widely abused, and, under some conditions, a loss of military power has resulted. Even when properly discounted for partisanship and overdramatization, it must be admitted that the Nye investigation brought out much evidence of the continuous activity and unsavory methods used by certain manufacturers of munitions in the United States and abroad to secure continued increase in armaments everywhere. Their willingness to sell to both of two contestants or to enemies of their own country has been all too frequently demonstrated. All the great powers have suffered injury from this international traffic in arms. German-built guns were sold to Germany's enemies and used to kill German soldiers. Torpedoes and submarines built by British-controlled munition plants are known to have destroyed French warships and British troopships during the first world war. "Secret" shells of new and startling power were patented in many countries by British manufacturers of armament a few years prior to the second world war. This procedure makes available invaluable information to friends and enemies alike through the medium of the Patent Office records for the cost of a few cents. The paradoxical nature of the system has been ably and unemotionally presented in a well-documented study by Noel-Baker to which the reader is referred for further information.(6)

The practices of the private armament manufacturers may lead to serious loss of military advantage. Actual loss in relative military power results when diffusion of military information and the stimulation of armament programs in enemy countries is supplemented by shipments of weapons and material that may be used against the country of their origin. State ownership of munition plants usually assures a military control, removes the profit motive, and normally prevents shipment of munitions to other countries until they become allies in war. The increased military power resulting from state control is so generally recognized that all countries, regardless of their peace-time form of government, adopt this policy during a war. Where such control also operates during peace or the time spent in preparing for war, it is an important factor in determining the relative military power of different countries.

As the technology of war advances, an ever greater dependence is placed on the industrial organization whose function it is to maintain a completely adequate supply of munitions for the troops. Modern war is truly industrial. A country having a multitude of

modern factories run by a skilled personnel has assets of inestimable value for the successful prosecution of a war. For modern nations, industrial power and military power march together.

The spirit of the people

The national characteristics of a people reflect environment, heredity, propaganda, and the influence of leaders, and thus also the philosophy of these men. These factors constantly change, and some of them may change quickly. Even inherited characteristics may shift rapidly when there is an influx of immigrants and a consequent change in stock.

Environment includes all the surrounding influences and forces that act on the people. Only a few can be considered here. Over a period of time geographic and climatic factors seem to impress definite characteristics on a people. Strength and hardihood are necessarily a residual legacy from a harsh climate and a rugged topography. A mountainous region that is difficult of access usually breeds a strong people but one that is insular and contentious. An easily won existence soon softens the unlucky fortunates and makes them an easy prey to marauders. The history of the Hebrews as recorded in "The Old Testament" illustrates again and again the inability of a nation to withstand the ravages of prosperity, and the increase in vigor and unity wrought by disaster.

Inventiveness, adaptability, and energy are among the most valuable assets a nation can have, if it is successfully to meet a rapidly changing environment. These are characteristics typical of the frontier. However, a frontier provides no leisure for cultural and scientific development, which is the essence of civilization. Both science and culture flourish in urban centers of wealth where the debilitating influence of luxury and leisure entail a gradual lessening of stamina, adaptability, and aggressiveness. The greatest advances are often made in those states that have both wealth and frontiers on which to draw. Out of such conditions arose Lincoln, Mark Twain, and Edison. Often when the frontier is settled a slow hardening of the arteries starts in the body politic.

Propaganda is used to create national unity and powerful cooperation in attaining national aims and also to stir up dissension and to weaken competing countries. The justification of propaganda when it distorts the true picture must always be that where the end is legitimate, and the means seem reasonable, it may be considered right to employ means that would otherwise be ques-

tionable. Leaders will use it to secure support; but to continue in power, they must be able to point to a rising standard of living; they must give those upon whom they depend for their power an increased feeling of security from things most feared, and, by no means least, an increasing feeling of self-importance.

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CHAPTER 2

Economics of the Mineral Industries

MANY OF THE operational and economic problems of the mineral industry are unique. There is a decided contrast in the engineering problems that face a production engineer in any type of factory and those that need to be settled by a man who must explore, find, blast out, and raise to the surface rock containing a small percentage of metal when that rock is thousands of feet within the earth. The difference between the economic problems of factory and of mine is almost as great, for the hidden and exhaustible nature of mineral deposits and their fixed geographical position give to mineral economics many peculiarities.

Features Peculiar to Mineral Economics

Localized occurrence

The mineral resources of a country are fixed as to location; they must be exploited where they occur or left to the future. Even such abundant and widespread deposits as coal and oil underlie only a very small fraction of our land. Although they are relatively common in some sections of the country, they are entirely lacking in great areas. The proportion of the earth's surface that is underlain by many other important minerals is infinitesimal. The molybdenum deposit at Climax, Colorado, is included within less than a square mile, but for many years approximately 85 per cent of the world's molybdenum came from the Climax mine. A similar proportion of the world's nickel originates in the Sudbury district, Canada, and most of the world's sulphur is produced from a few small camps in Louisiana and Texas. Even blanket deposits, as coal, are concentrated in restricted areas; and many nations have none at all.

The countries within whose boundaries such mineral treasures lie possess temporarily an asset that gives them a great commercial

advantage over their less fortunate trade rivals. As long as the minerals can be dug up and profitably converted into fabricated goods, trade booms, and the lucky owners become increasingly wealthy. However, in the course of time, this condition must change because of the wasting mineral assets on which the enterprise is based. Productive mineral deposits are among the most valuable resources that a nation may have; but such an asset will be widely coveted, and serious international problems may be engendered by the mineral policies of the government that controls the deposits. Expatriation of the American- and British-controlled oil industry in Mexico precipitated an international crisis that might easily have led to another landing of United States marines at Vera Cruz.

Exhaustibility

Each individual deposit has its limits, and if it is worked long enough, it must sooner or later be exhausted. The mineral industry contrasts sharply in this respect with agriculture and silviculture. Some of the farmlands of China and Europe have been producing food throughout recorded history. Silviculture has made forests perennial sources of timber in many European countries. Rubber trees may be smuggled out of Brazil to start a great plantation industry in the East Indies, or sent back from the eastern hemisphere to start new plantations in Haiti. But the harvesting of iron ore, coal, or limestone leaves only holes in the ground for the use of future generations. There is no second crop of minerals, but sometimes improved technology allows renewal of work in deposits that had become unprofitable to exploit.

Before a mine is exhausted, all the money invested in it should be paid back with a profit. Thus, amortization, the liquidation of a debt by means of a sinking fund, is an essential part of mineral economics. The purchase price, the cost of plant and equipment (less resale value), must be amortized and in addition a profit should be realized. The sinking fund is supposed to be an accumulation of payments made at set intervals, together with the additional money represented by the accumulating interest on the fund. Actually a sinking fund is rarely set up as such; money equivalent to the sinking fund is paid as part of the returns to the investors. Buying automobiles or refrigerators or a diamond ring on the installment plan consists in paying someone else a substantial fee to see to it that you amortize the debt.

In addition to using sinking funds for amortizing the cost of acquiring a property with wasting assets, sinking funds are commonly used to amortize equipment charges, which may be of a recurring nature. In fact, depreciation may be figured in the same way as is a sinking fund. The amount of depreciation is usually figured conservatively; as a result, the amount set aside or written off each year to allow ultimate replacement is generally much more than enough to take care of obsolescence. The large corporations have built such tremendous reserves by this method that they are now internally financed, and it is no longer necessary to float bonds to pay for the construction of even very large new plants. The fund for depreciation of the United States Steel Company now amounts to more than a quarter of a billion dollars, a sum ample to finance the construction of even large new additions to plant and equipment.

Increase of costs with depth

The continued extraction of ore from nearly all deposits leads to increasing costs as the material mined is taken from greater and greater depths. Continued production from any mineral deposit is accompanied by increasing costs per ton. Open pit mining of iron on the Mesabi range costs less than seventy cents per ton; iron mining in northern Wisconsin and Michigan, where the ore must be hoisted three thousand feet to the surface, costs from two to three times as much. The cost of raising oil in a flowing well is reduced to the cost of supervision, wear, and attendant replacements of well fittings. This cost is usually less than a cent a barrel. In contrast, the cost of raising oil in a pumping well commonly runs from five to fifty cents a barrel. The cheapest oil to raise is that which comes during flush production. As the output diminishes, the cost per barrel steadily rises.

The sources of supply for the trade in minerals have changed many times in the past; some changes, therefore, should be expected in the future. A shift in the source of supply may be due to the gradual exhaustion of individual deposits or to the competition of newer and more cheaply operated properties in a different place. Some important industrial minerals, such as coal and iron, are present in enormous quantities in certain regions; here the question is not one of exhaustion but of cost that increases with depth. As the costs rise, the competition with other deposits more favorably located or more cheaply worked becomes increasingly bitter.

Profits diminish, wages are cut, and the living standards of all concerned suffer accordingly.

The discovery, development, exploitation, and exhaustion of a mineral-bearing region entails a fairly definite social and economic pattern. (See Figure 1.)

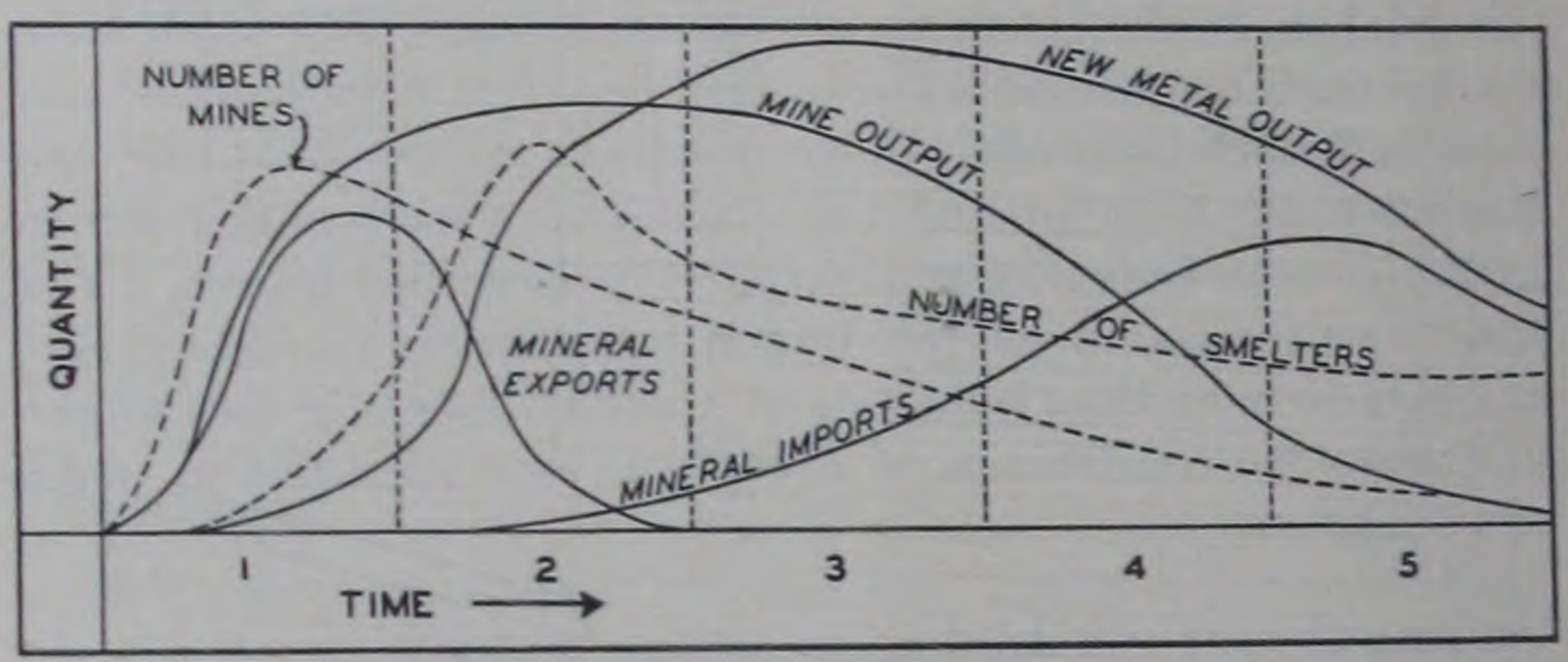

Fig. 1. Stages in the mineral and metal production of an industrial country. (Modified from Hewett.)

Hewett,(2) who has analyzed the normal history of mineral exploitation in a nation, recognizes several successive overlapping stages in the growth and decay of metal production:

1. Period of mine development: exploration, discovery of new districts, boom towns, many small mines working; first recognition of large deposits and development of the large mines; rapidly increasing production of metal.

2. Period of smelter development: few new discoveries; small mines becoming exhausted; increasing output from large mines; many smelters competing for the ore.

3. Period of industrial development: decreasing costs, increasing standard of living; rapid accumulation of wealth; expanding internal and external markets; approaching zenith of commercial power.

4. Period of rapid depletion of *cheap* raw materials at home. This involves ever-increasing costs of mining and of minerals produced; more and more energy is required to get the same amount of raw material. The stage is set for a bitter commercial struggle with competing sources of raw materials; some foreign markets are lost; some foreign goods invade the home market. Usually some auxiliary raw materials first appear (agricultural products and

minerals). Later, competing manufactured goods of foreign make begin to usurp the home markets unless temporarily blocked by tariffs.

5. Period of decreasing internal and external markets. Increasing dependence on foreign sources of raw materials brings increasing costs to manufacturers. This stage is characterized by a decreasing standard of living with its accompanying social problems and political unrest; tariffs, subsidies, cartels, and other artificial expedients are used in the effort to maintain a competitive price in the domestic and world market. This is a period of decreasing commercial power. It is a time when military pressure may be used to strangle competition or to seize control of new sources of raw materials. A drive is generally made to acquire cheap foreign sources of raw materials when the domestic sources become low. Commercial control is first established, but political control may follow later. Commercial control of foreign sources of supply keeps the profits within the home country, helps to maintain purchasing power, and assures a supply that will be as cheap as can be obtained. Control of foreign sources also gives the owner an obvious advantage in dealing with competing nations that also need the raw material in question. The pursuit of this advantage has frequently led to international friction.

In a general way it may be said that in 1938 Rhodesia was in stage 1, Canada was entering stage 2, the Soviet Union was near the end of stage 2, the United States was nearly through stage 3, Germany was in stage 4, and Great Britain was in stage 5.

Discovery hazards

Some ore bodies are visible at the surface, but many are completely hidden from view. The search for new deposits is never-ending, but their discovery is infrequent and requires much skill or even luck. A new "strike" often proves to be a mixed blessing. The finder may reap a rich reward while others working marginal deposits near by are put out of business. Thus, two types of discovery hazard appear: too little may be found by one man and, from his viewpoint, too much may be found by someone else.

Undersupply hazard. It would be most desirable to have complete knowledge of the size, shape, and grade of a mineral deposit before a pick was put into the ground. With a few simple types of ore bodies, this desideratum may be nearly attained; but if the

geology is complex, the ore reserves that are known at any one time may be only a small part of what is actually present. The difficulty of geologic interpretation may require a constant search for extensions of ore throughout the life of a property. Similarly, the rapidity with which some deposits are used up makes it essential to discover new ones. If an organization is to have a longer life than that of an individual deposit, new properties must be found and developed. This is an especially pressing problem for oil companies, because of the rapid production decline of individual wells. Many of the major petroleum producers spend millions of dollars annually in the search for new oil fields.

The discovery hazard is always present in some form, even for those concerns that do not anticipate a life beyond that of a single deposit. Unforeseen geologic factors may substitute a large block of barren ground where engineers anticipated ore; and happily the converse is sometimes true. If the estimate of ore was poor, the life of a mine might be so short that the investment could not be amortized.

Oversupply hazard. If large or more cheaply worked deposits are found, some that were formerly profitable may become noncommercial. The successful exploitation of a mineral deposit depends on many things, but chiefly on its grade, size, and location. All of these factors affect the margin of profit. At any given time, a great range in the spread between costs and market price for different producers will exist. In 1930, the cost of producing copper in some Michigan copper mines was twenty-three cents per pound; but the low-cost western open pit mines of Nevada Consolidated Copper Company and Utah Copper Company were producing the metal at a cost of only seven cents a pound.

Marginal producers are those who operate without a profit or at a loss but who carry on in the hope that market price will rise and put them in the black. No matter how high the price is set, there are always marginal producers. The bottom limit to which the market price will sink during a depression generally approximates the cost of producing the mineral in the lowest cost properties. The marginal producers are usually the vocal minority that bring pressure to bear on their government for tariff protection or some other form of subsidy. The communities dependent on marginal producers always face less than average wages and a gradually declining standard of living. There is the further danger that a population will become stranded with little means of support other than

government subsidies, except in times of unusually high prices. It has often been proved that home owners are amazingly reluctant to desert properties in stranded mining areas, even though they have full knowledge of the existing economic conditions. Out of these factors arise some of a country's most difficult social problems.

Where any industry that employs many workers has become so uneconomic that a shutdown is inevitable, a comparatively large-sized group may face the loss of its essential support. If the shutdown is permanent, the problem of the "stranded population" imposes itself on the larger community, which may be a county, a state, or a nation. Where intermittent shutdowns can be foreseen, as in the iron and coal industries, some means of lessening the economic shock of the shutdowns may be devised. In northern Michigan, the iron companies have set up glove, corset, and powder manufacturing plants where women of the community and some of the miners may find employment during times when the mines are idle. In Pennsylvania, some coal miners work part time in co-operative handicraft centers.

It is plain that discovery of new deposits, whose grade, size, or location permits a substantial new output to be made at a lower cost, will adversely affect operation of marginal producers. The phenomenal success of copper-hunting geologists from the United States and Britain, who sweated through the hot African brush in Rhodesia and the Belgian Congo during the nineteen-twenties, contributed much to the decline of the great copper district of northern Michigan. As the enormous African deposits came into production in the early thirties, only the low-cost copper mines in the western United States found themselves competing on equal terms. When the average price for copper dropped from seventeen cents per pound in 1929 to six cents in 1932, many mines that had been operating profitably for years suddenly found themselves transferred to the class of marginal producers. Such mines as had been optimistically hanging on as marginal producers in 1929 were forced to close down without hope.

The discovery of large new oil fields may cause the generally accepted "laws" of supply and demand to break down altogether. Oil is a "fugitive" mineral; it moves easily underground and may cross property boundaries with complete lack of consideration. The laws concerning it recognized an owner's "right of capture" for any fugitive substance whose movements were as unpredictable as those of underground water or oil. As a result, it was possible

and allowable to drill a well close to a boundary line in the expectation that oil would be taken from under the adjoining property as well as from under that in which the well was located. If the owner of adjoining land failed to protect himself by drilling an "offset" well—one located as close to the other as his boundary permitted—the oil might be entirely drained from under his property. In practice, this "right" led to wasteful overdrilling and to production on nearly all leases whenever any one well started. Even though the price were so low that all wells operated at a loss, no one would stop and thus sustain a possibly larger loss through the movement of his potential supply into a neighboring well. Normally the price of crude oil is about a dollar a barrel in Texas. When the East Texas field was brought in during the depression of 1931 to 1934, its unrestricted production ran up to one million barrels a day and flooded the market. The price dropped continuously to an all-time low of five cents a barrel! Only intervention of the state forced the operators to suspend their ruinous overproduction and saved the oil industry from complete demoralization.

Expendable and nonexpendable minerals

Expendable minerals include those that once used are in large part destroyed or made into a form in which they cannot be recovered. Coal, petroleum, and mineral pigments are examples of expendable minerals. Nonexpendable minerals include those that can be reused many times, such as gold, iron, and lead. Some of the gold stored by the United States Treasury at Fort Knox in Kentucky may have been part of the treasure of Ramses. When the article in which a nonexpendable metal is employed becomes obsolescent, it can be sent back to the furnace as scrap and reused.

Two different types of scrap are distinguished: *home scrap* and *market scrap*. Home scrap is leavings from the table of the local industry; it comprises the trimmings and waste that normally accompany a manufacturing process. Market scrap is the metallic garbage of the country. When an article can no longer be used, its value sinks to that of the materials of which it is composed, less the cost of reclaiming them, and comes onto the scrap market for bids. Scrap is the governor on the price engine of metals. Just as a mechanical governor prevents any sharp changes in speed in a steam engine with varying loads, so does scrap prevent any sharp fluctuations in the price of the nonexpendable metals. An increase in price

tends to bring out more scrap as well as more virgin ore. As prices rise, the metals in use where obsolescence is approaching may become more valuable as scrap than as part of an inefficient or outmoded appliance. In all industrial countries a reservoir of deteriorated equipment is available for scrap in times of emergency. In 1917, during the profit taking which accompanied that world war, the price of steel advanced to a point where more could be realized from sale of the Colorado Midland Railroad as scrap than from its operation. Its right of way was stripped of rails which were sent back to the steel furnaces, and its roadbed was soon being used as an automobile highway.

Economic Factors Common to Mineral and Manufacturing Industries

Each branch of the mineral industry has certain individual peculiarities; but the industry as a whole shares with other business the problems of marketing and production costs. Market prices depend largely on the following factors: demand, supply, cartels, prices of substitutes, market speculation, and production costs.

Demand

The demand for mineral products comes chiefly from the manufacturing industries. A reserve stock is always kept on hand to provide for smooth functioning of industrial plants. The constant arrival of large quantities of raw materials is essential to maintain this local stockpile during a period of increasing business volume. The larger the manufacturing output, the larger should be the reserve. However, when the output of manufactured goods begins to decline, the relative reserve of raw materials will increase with disproportionate speed unless the supply is cut below immediate requirements. Thus, in the business cycle, mineral products are among the first commodities to be cut by the manufacturing industries in the drop toward depression and one of the last things to be added in the climb toward prosperity. The result is that price and production curves of minerals are more highly accented than those of the industries that use these raw materials.

The effect of war on mineral production and prices is even more pronounced than in other industries. Certain minerals whose output is in the control of a small group and which are essential to war may double in price over night. Thus the price of mercury (controlled by a Spanish-Italian group) rose from about a dollar a pound on September 2, 1939, to two dollars a pound on September

5, 1939. Mercury finds its principal uses as a source of antiseptics and other medical supplies and in the manufacture of blasting caps and detonators.

Viewed over a period of time, technological improvements both in the industries that supply and those that consume minerals have a pronounced effect on demand. The gradual improvement in oil refining allowed the production of three times as much gasoline from a barrel of oil in 1940 as was possible twenty years before. To furnish the United States alone with its normal quota of gasoline by the older processes would have demanded 50 per cent more oil annually than was then produced by the entire world. Technology may be classed as one of our most important conservation measures. Improvements in efficiency of engines tend to decrease the demand for fuel, but the efficiency curve approaches a limit beyond which it cannot rise. The effect of the improvements becomes less and less noticeable on demand for fuels as the efficiency nears this limit. The fuel savings effected by railroads through increased efficiency of engines between 1919 and 1935 was nearly 50 per cent. It is obviously impossible to effect a similar saving between 1935 and 1951.

Supply

An oversupply of metals produced as by-products may be instrumental in setting price. For many years platinum was supplied to the world market by properties worked for platinum alone. During that time the price fluctuated violently but showed a general increase; from a low point of 28 dollars an ounce in 1910 the price climbed a zigzag course to a high of 155 dollars in 1920 when platinum from Canadian nickel ores of Sudbury began to be saved as a by-product of nickel refining. During the next decade, as the technique of separating the platinum improved and increasingly large quantities appeared on the market, the price of platinum dropped to about 35 dollars an ounce and has hovered near this value since, except for a brief period in the winter of 1936–1937. From the position of a virtual nonproducer in 1920, Canada rose to second place in 1938, when by-product platinum from the Sudbury nickel ore made up more than a third of the world's total.

Scrap is an important source of supply for many metals. From 15 to 50 per cent of some metals is furnished by scrap in the United States. In certain foreign countries almost all of the metal used may come from scrap. The blast furnaces of Japan, Italy, Argen-

tina, and various other countries depend in large part on scrap. The great reservoir of potential scrap that is always present in an industrial nation can be tapped at any time by raising the price of the metal in question. A similar but less quickly available reservoir of raw material is found in marginal producers, whose activity and numbers are greatly stimulated by a price rise. Scrap metal and marginal deposits tend to keep metal prices stable.

Cartels

A cartel, as the word is generally used in the mineral industry, is a written agreement between different producers or marketers to regulate production or sale so as to maintain a certain price. For effective operation, the major part (usually not less than 75 per cent) of the world's production must be covered. It is difficult to obtain the consent of an owner to the decreased output of a commodity that is being profitably produced. Cartels seldom last for more than a short time and are usually ineffective; but a few have succeeded in stabilizing artificially the price of a metal for a period of years. Among the most successful have been the Aluminum Company of America, with its numerous affiliates and subsidiaries, which maintained the price of aluminum at about 22 cents a pound for many years. Noteworthy too is the tin cartel, controlled by British interests, which raised the price of tin from about 20 cents a pound to 50 cents during the depression and were able to hold it at this level for years.(5, 6) Although the United States is the largest consumer of tin in the world, it produces much less than 1 per cent of its requirements.

Another form of cartel is the agreement between governments as to the value of monetary metals. The United States buys all gold offered to it at a fixed price of $35 an ounce. Before the government set this price in 1933, gold was bought at the fixed price of $20.67 an ounce. The increase in the price of gold was of great importance to the major gold-producing countries of the world—the British Empire, the Soviet Union, and the United States. A mine that worked on 10-dollar ore at the old price and made a profit of 50 cents per ton would, under the new price, be working ore worth $17.50 per ton. The rise in costs due to inflation was so small that its profits would be multiplied many times and would probably approximate $5 a ton. Without the artificial price maintained for gold by the United States, industrial bankruptcy and chaos might result in the great gold-producing capitalist countries such as the

Union of South Africa and Canada, as well as in the industrial nations that exercise a large degree of commercial control over them, as do Great Britain and the United States, respectively.

At times there may be two prices for a metal. For many years the United States government has paid a relatively high price for newly mined domestic silver—about twice as much as the commercial market value of the metal. This price is also paid to certain "favored nations" for their newly mined silver, so long as it seems to be to the interest of the United States. Other silver mined outside the United States and silver scrap are worth only about 35 cents an ounce.

Substitutes

Satisfactory substitutes for almost all raw materials exist, if the price of the substitute is not a consideration. When a mineral is said to be essential to industry, underlying qualifying assumptions may often be unrecognized: 1) a mineral may be essential to the production of the *most* satisfactory type of product; or 2) it may be essential to successful *commercial* competition in the world market. If a less satisfactory product can be made cheaply enough, the substitute may usurp the place of the better material. Pound for pound, aluminum is nearly as good a carrier of electrical power as is copper; although normally it is not used for this job, hundreds of miles of aluminum cable were purchased during 1929 and 1930 when aluminum was cheaper than copper. Such substitutions have an obvious effect on the price structure. The second tacit assumption stated above is illustrated by the canning industry of the United States. Here most of the tin is used as tin plate in preserving food in the well-known "tin can." Other containers might be used, but none would be as economical and satisfactory as the tin that is available at fifty cents a pound. However, when a housewife cans vegetables or fruits, she generally uses glass jars rather than tin cans.

Sometimes technologic improvements or new inventions create an entirely satisfactory substitute that is economical. If the substitute can be produced at a sufficiently low price, it may largely displace the natural raw material. This was true when synthetic nitrates were successfully developed and substituted for Chilean nitrates. We may expect a substantial reduction in the amount of tin used in normal times by the canning industries if the use of frozen food increases.

Whenever the price of a raw material is maintained at a high

level or there seems danger of a scarcity developing, much time and money are spent on the search for satisfactory substitutes, usually with ultimate success.

Market speculation

Market speculation affects the price of mineral raw materials in the same way as it does other commodities. Concerted buying in anticipation of higher prices accentuates the upward trend just as, conversely, a general feeling that the market is dropping results in slow sales and a more rapid decline in price.

Production costs

Production costs depend largely on financial costs, maintenance costs, operating costs, and amortization. Each of these is a special study and each varies with the individual enterprise. Space cannot be given to their proper consideration here.

The Place of Minerals in a National Economy

Relative importance of minerals

The minerals that have been most essential to civilization in the past include coal, iron, and copper; but to these three, petroleum must now be added. They represent energy and the two metals most basic to manufacturing. The direct and indirect contribution of the mineral industries to wealth and power is enormous. In the United States, the leading industries named in the order of their normal revenue are 1) manufacturing, 2) agriculture, 3) mineral industries, and 4) transportation. During an average year of the nineteen-thirties, the portion of the national income derived from the mineral industries was only slightly larger than that obtained from transportation, about one-half that derived from agriculture, and from one-fourth to one-fifth that contributed by the manufacturing industry.

As much metal has been mined since 1905 as was mined in all previous history. The white population has increased threefold since 1800, but its demand for metals has increased a hundredfold in the same period. The demand for minerals depends on manufacturing and on power consumption; but, as already noted, production is partly independent of demand. Local production is determined by the economic conditions appertaining to the local industry. Most large-scale operations are relatively inflexible, and

continued operation at a small loss may be preferable to the large loss caused by a shutdown. Neighboring wells must produce oil if one well produces. The production of by-product metals, such as the platinum obtained from refining the Canadian nickel ores, comes onto the market regardless of demand for the auxiliary metal.

Strategic, critical, and essential minerals

Prior to 1939, about 80 per cent of the production of the twenty-eight chief minerals of commerce was consumed by the industries of only eight nations: the United States, Germany, France, the United Kingdom, the Soviet Union, Japan, Belgium, and Italy. Competition among these nations for control of mineral supplies was as unceasing as competition for the markets of fabricated products.

Cheap raw material is essential to cheap finished products. No nation is self-sufficient in raw materials, and numbers of minerals used in manufacturing have no satisfactory or economic substitutes at the present time. The essential minerals in which a nation is deficient are commonly called the war minerals. The war materials are divided into three groups: *strategic*, *critical*, and *essential*.

Strategic minerals are those that are necessary to industry and that are not and cannot be produced at home in quantity sufficient to satisfy normal industrial demand. They include the most necessary deficiency minerals supplied by foreign sources in normal times. This list differs for each of the great powers, and changes from year to year for individual nations. The strategic minerals listed for the United States and the amount of our requirements supplied by foreign sources prior to 1940 was as follows: tin, 99.9 per cent; chromium, 99 per cent; nickel, 99.5 per cent; tungsten, 50 per cent; manganese, 90 to 95 per cent; antimony, 90 per cent; and mercury, 60 per cent. Extensive field work by the United States Geological Survey and by the Bureau of Mines beginning in 1939 has moved several of these minerals from the strategic to the critical list.

Critical minerals include those essential to industry that are normally produced in too small a quantity to satisfy the domestic demand, but of which known undeveloped supplies seem sufficient to take care of national needs during an emergency, with its attendant price rises and stimulation of output. This list includes minerals of which there is no exportable surplus, and that usually are supplied only in small part from abroad. When the United

States entered the second world war, this list included chiefly aluminum and potash.

The *essential* minerals are those most vital to industry that are usually produced in sufficient quantity to yield an exportable surplus. Essential minerals would be regarded as sufficiently important to the conduct of a war to justify military attention and, if expedient, official regulation. In the United States, this list in 1941 included coal, iron, molybdenum, petroleum, copper, lead, and zinc. However, it must be realized that during a war production of these metals, no matter how large, will be inadequate to satisfy the desires of war-geared industrial plants. Even though output doubles, a shortage will still exist.

All countries are striving to achieve greater self-sufficiency, and the degree to which a country depends on foreign sources of supply varies greatly. Importation of a given mineral may be caused by: 1) a slight deficiency; 2) a shortage of commercial grade; 3) the consuming centers being favorably located relative to foreign rather than to domestic production; 4) domestic extraction costs being higher than those of foreign deposits; 5) an actual lack of the mineral. Imports of aluminum, manganese, coal, mercury, and tin into the United States afford good illustrations of these differences.

The United States is only slightly deficient in *aluminum* ore, yet approximately 60 per cent of our needs is imported. The ore is supplied by countries that can ship it cheaply by sea. We possess substantial reserves of aluminum ore, but the largest deposits are in Arkansas, remote from cheap oceanic transportation.

The United States has a large amount of low-grade *manganese* ore but not much of commercial grade. Only a few deposits of ore are good enough to be used for the manufacture of ferro-manganese, an alloy indispensable to the steel industry. As a natural consequence, we usually import most of our requirements.

Coal is imported into central Canada from the United States in large quantities; nevertheless, Canada also exports coal to the United States. The New England states are served in part from Nova Scotia because the transportation costs are less than for coal from Pennsylvania, West Virginia, or Virginia.

The cost of producing *mercury* from our low-grade deposits was disproportionately high before Italy and Spain raised the price in the fall of 1939. Therefore we imported a substantial amount of mercury from these countries.

We import *tin* because we have virtually no deposits of this metal.

If the price rose from fifty cents to fifty dollars per pound, we would still be unable to produce our normal consumption requirements.

National mineral policy

The mineral policy of most nations has definite objectives:

1. To obtain revenue, especially from products on which there is a national monopoly.
2. To facilitate low-cost imports for the manufacturing industries.
3. To secure a market for low-cost exports.
4. To protect from foreign exploitation mineral deposits that are inadequate or scarcely adequate to meet demands in time of war.
5. To protect domestic producers from foreign competition where the domestic mineral supplies are ample.

These policies all tend toward nationalism.

Minerals have always been an important source of state revenue. In some countries, the mineral rights belong entirely to the state and cannot be sold to private owners. The right to work the deposits is given to individuals or groups, and royalty and rents are collected as extraction proceeds. Taxes may be added, also, but this device is especially designed to raise revenues from property that does not yet belong to the state. Taxes may be made so prohibitive that the property cannot be operated by private capital and must be relinquished to the state. It is also possible to expropriate mineral lands and agree to pay the owners for their equipment and mineral rights. The deposits can then be worked by the state, or leased by it to private enterprise.

Although taxes and royalties are seldom critical items of expense during flush production, they become prohibitive as a mine or oil field nears exhaustion. The stability of a government and its attitude toward exploitation of mineral resources is regarded with deep concern by anyone contemplating a large investment in its mineral lands. Both Argentina and Mexico have at times adopted the policy of mineral industry expropriation. It is natural that the loss of profitable business and the delay in receiving reimbursements from these governments would make the corporations involved hesitant to risk money where they believed such action might be taken.

Taxes may be assessed against mineral reserves, mineral stored at the property, and shipments made. According to an old British

saying, "The science of taxation is to so pluck the goose that there is a maximum of down and a minimum of hissing."

Because of the vital part played by minerals during a national emergency, it is important for a nation to be prepared to cope with mineral deficiencies. The methods that can be used to assure adequate supplies during such a period include the following:

1. Stockpiles of deficiency minerals may gradually be acquired by purchase or barter.
2. Peace-time production of essential or critical minerals may be expanded in preparation for war.
3. Existing supplies of strategic minerals may be conserved in peace time by restricting their production. Removal of tariff protection is generally enough to accomplish this end.
4. Scrap may be conserved for a potential supply by forbidding its exportation.
5. Recovery of secondary metal may be encouraged and new sources of scrap sought.
6. The uses of strategic minerals may be restricted to those that seem most essential.
7. Substitutes may be sought.
8. Efforts may be made to stimulate the output of foreign sources that will probably remain accessible during a period of stress.
9. Diplomatic or military operations may be used to make available sources of supply from reluctant but accessible foreign sources.
10. It is customary to accumulate information during peace time on foreign and domestic sources that may be tapped during an emergency, as well as on the requirements and sources of supply of potential enemies.
11. Preparations may be made for possible sabotage or shutdowns during a war, for the possible loss of certain sources through invasion, and for the loss of sea-borne freight during a war.

In a time of emergency, the government may be expected to assume control of prices, production, and distribution. It will use whatever methods seem most expedient to increase the domestic output and supplement them with an adequate foreign supply.

It has only been in the past few years that the United States has tried to formulate a definite mineral policy. Largely through the advice of C. K. Leith, the United States government in the late nineteen-thirties began to shape a definite policy that considered

the domestic sources of supply with regard to the development and production for each mineral needed by industry. The policy recommended differs with the mineral and depends primarily on its abundance and accessibility.

Minerals in which we seem to be deficient should be conserved; at the same time, inducement should be made to find and develop new deposits. This can be done by subsidizing production and holding the ore in a government stockpile. Commercial needs might still be satisfied from cheaper foreign sources. In addition to stimulating search by setting an artificial high price, government agencies such as a Bureau of Mines or a Geological Survey can be employed to locate, to test, and even to develop new deposits of the deficiency minerals. This has been done in the United States, the Soviet Union, and a few other countries with marked success.

Selective tariffs and cartel controls can be used to stimulate domestic production where there is an adequate supply but inadequate production of some mineral.

Minerals that are normally exported need cause no concern as to the adequacy of their supply.

Some have advocated that the War Department acquire marginal producers by purchase, so as to have a reserve for times of national emergency. Such a move would also relieve the pressure for tariff protection that owners of such deposits always bring to bear on their government. A protective tariff, of course, "protects" one group at the expense of another. The higher price transfers an unnecessary load to some other part of the national economy. Because of tariff protection for United States tungsten mines, the manufacturers of tungsten steel in the United States have paid 100 per cent more for their tungsten than did their German and British competitors.

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CHAPTER 3

Minerals in History Before the Industrial Era

Trade routes and the struggle for commerce

THE PATTERN of human behavior is generally determined by desire for individual or national security and the inclination to achieve this end with a minimum of risk and the least possible work. Articles that give their owners a distinct advantage in the struggle for existence have always been eagerly sought. Obsidian arrowheads from the Yellowstone Park area were used by Indians in what is now Ohio long before Columbus was born. Jade arrowheads, prized for their toughness, moved from Khotan in the Gobi desert of Asia to Germany in prehistoric times. Commerce of this sort established definite routes thousands of years before recorded history.

As early civilizations developed, their more complex needs resulted in increasing traffic. Large numbers of people became dependent upon the business of transporting goods from one region to another; and where two routes crossed, cities sprang up and flourished. As the cost of transportation depended primarily on the ease, speed, and safety of travel, the protection of trade cities and of the trade route itself was essential to its use. If a choice of routes was possible between two centers of exchange, intense competition arose between the rival transport systems. In ancient times, as in modern times, this economic competition often blazed into war, as the rival systems tried to destroy each other, first by economic means and then by force. Changes in the source of materials and in their destinations, discoveries of new routes or the development of inventions making possible new routes, have led to many shifts in the major avenues of commerce, and each shift was a calamity to some nation.

Because of the geographic distribution of natural resources, it is inevitable that certain portions of the globe will supply articles of

commerce needed in other regions. Topographic features will always influence trade to move along some routes, but as suggested above the amount of commerce may fluctuate greatly from one age to another. The power of nations dependent on trade routes increases or ebbs with the commerce from which they gather their strength.

Markets are closely related to population density. Either a fertile soil or a successful manufacturing center may support a large population and produce wealth. The two industries are complementary: exchanges between them are the life blood of commerce, trade routes the arteries. Although the great agricultural regions remain relatively fixed, the industrial centers may shift. Successful manufacturing requires cheap raw materials. If the sources of the raw materials change, the manufacturing centers may move too, though with a reluctance engendered by the great inertia of invested capital.

Few inventions have so stimulated the manufacturing industry as those that have advanced the art of smelting metals. Smelters require fuel, ore, and flux in proximity or tied closely together by cheap transportation. Since it is usually more expensive to move fuel to ore than vice versa, cheap and suitable fuel generally determines the location of the smelting center. Until a few hundred years ago, this meant that forests were needed to furnish charcoal.

Throughout history, the successful search for ore has expanded the periphery of empires while populations became concentrated in smaller and smaller areas within them at trade-route termini or crossings. The geography, the natural resources, the character of neighboring peoples all offer different inducements to expansion or oppose a variable resistance to it, and the result is irregular growth. Extension of an empire's boundaries usually follows the path of least resistance; but the movement of each empire has been directed toward acquiring centers of wealth, and rich mineralized areas have been one of the more frequently coveted prizes of both ancient and modern nations.

Early use of minerals

Man has existed with much the same mental and physical capacities for thousands upon thousands of years. How long ago he began using minerals for tools and weapons is hard to say, but thirty thousand years is not an unreasonable estimate. Man, in common with other animals, was using salt even before that time.

The great salt deposits of Germany have been the cause of strife from prehistoric times to the present. During the life of Caesar, when recorded history first singles them out, German tribes were fighting bitterly for the possession of these "saltz stocks." Salt deposits, or salt springs, helped determine the route of trade for more advanced peoples much earlier. The salt of Palmyra was an important factor in trade between Syria and the Persian Gulf when Babylon was a thriving city. Salt was obtained in sufficient quantities from the salt springs of the Libyan desert and of southern Russia to be an important article of commerce at the time of Alexander the Great, in the third century B.C. It was such a necessity that it gave its name to one of our most modern indispensables, *salary*, which was at first the money paid to a Roman soldier to buy his needed salt. The query, "Is he worth his salt?" had its beginning when the commodity was much more valuable than it is in most places today. However, in some places in Africa it is still at a premium. Natives of Abyssinia customarily exchange four chickens for one pound of salt.

The minerals used during the Stone Age stage of culture were many. Certain of them, such as the jade arrowheads already mentioned, were very highly valued. Flint is a fairly common mineral, but good deposits are localized in relatively small and scattered portions of the earth's surface. The making of flint weapons was probably the first manufacturing industry. Its products spread by exchange and theft for hundreds of miles from the places where flint was dug out of the ground.

Metals were first used by man as ornaments. Gold was probably the metal discovered earliest, as it occurs in nuggets of native metal in many streams, and its color and luster would arrest the attention of the most primitive man. So soft and malleable that it can be easily worked, it lends itself naturally to the first use to which primitive man put it. A few other metals, such as silver, copper, and the iron in meteorites, are found in a metallic state in nature, but most of them are combined with other elements in the form of sulphides, oxides, or silicates and must be obtained through smelting. Native copper, like gold, was used as an ornament by Stone Age man; but because of its greater hardness, copper was soon used for more practical purposes. Copper weapons were much superior to those made of stone, so it was not surprising that, in man's perennial desire for increased security, he fashioned native copper into knives, arrowheads, and spear points. The art of hardening copper

by hammering was known to the Chaldeans about 4500 B.C., nearly 6,500 years ago.

The discovery of the principles of smelting was probably accidental and the same discovery was undoubtedly repeated by many different people at widely separated places. Geologists have recently reported that small fires produced globules of metallic copper where natives kindled them directly on outcrops of the copper oxide ores of the Kantanga district in Africa. Such lucky accidents in the remote past probably led to intentional reduction of metallic ores with heat and charcoal. During forest fires, the oxidized silver minerals at the outcrops of silver veins may be reduced from dark earthy appearing substances to bright metallic silver. American prospectors in the last century often deliberately set fire to a forest to "brighten up" the outcrops and were sometimes enabled to find rich silver veins in this manner. It is probable that the silver veins of Spain were first found in this way.

Only in the past century did smelting begin to change from an art to a science. Before the development of analytical chemistry, little was known about the actual composition of smelter products. Because ores from a given locality were likely to be fairly similar in composition, the smelted ore, although unlikely to be pure metal, would also be fairly uniform and would possess certain properties. Certain alloys were thus characteristic of certain localities. Tin and copper are closely associated in many ores, and as they are the constituents of the alloy, bronze, it is not surprising that bronze was produced at an early date in what is now Cornwall, Bohemia, and western China where such ores occur. Similarly, the primitive smelting of zinc-copper ores, such as those containing calamine and native copper, may have yielded brass. It was a long time before ores were deliberately mixed to obtain a desired product, and still longer before metals were separated and refined or intentionally mixed to obtain an alloy. Although bronze was used in Europe before 2000 B.C., the intentional manufacture of this alloy began about five hundred years later in Egypt.

The smelting of iron was beyond the technical skill of man for thousands of years after he was able to reduce the ores of copper, silver, lead, mercury, and tin. Metallic iron was obtained from meteorites and wrought into swords for the early emperors and kings. Attila, Timur, and various Caliphs are known to have carried these "swords from Heaven" as one of their most valued possessions. One of the earliest records of iron weapons is that which refers to the iron knives used in Palestine about 1350 B.C. Such iron

was not smelted in the true sense of the word, which implies melting of the metal; rather it was hammered out at a forge with great labor from a hot, somewhat plastic mass of slowly reducing ore, slag, charcoal, and metal. Actual smelting was not accomplished in Europe until about the fourteenth century.

For a long time metal weapons were only for the rich and powerful. Many soldiers of Xerxes' army were still equipped with stone weapons. The use of metal for peaceful occupations slowly followed its introduction as a material for improving armaments. Its value in both peace and war needs no proof; few things have been more eagerly sought by nations or more neglected by historians.

Ancient Egypt

In the fourth millennium B.C. the petty Egyptian states along the Nile were consolidated into the Upper and Lower Kingdom; and about 3400 B.C. they were finally united by Menes, the earliest of the Pharaohs, into a single kingdom. It was not until six centuries later that Egypt first emerged as a great power of the ancient world, and the buildings, pyramids, sculpture, ceramics, and customs of this period indicate its rapidly developed culture. It should be remembered that the glory of ancient Egypt as pictured by archeologists is the "glory" of a small and ruthless group of wealthy nobles. The toiling millions who lived in abject poverty were not described on the boastful stele of a Pharaoh. The luxury of the kings and the rapacious priesthood was in hard contrast to the existence of the workers and slaves.

Egypt had little of worth within her original borders except the fertile valley of the Nile. The forests, silver, tin, gold, copper, and iron of the West were all lacking. Neither did she have the spices, silks, perfumes, gems, ivory, myrrh, incense, and ostrich feathers of the East and South. To secure these commodities, she used the age-old expedient of force. About 2800 B.C. Snefru became king of Egypt, and early in his reign he invaded the Sinai Peninsula and obtained the Maghara copper and turquoise mines by conquest. At that time, copper was about as valuable as gold. A hundred years later Sargan took the Isle of Cyprus and began exploiting the rich copper deposits there, one of the most important sources of the metal in ancient times. The rich gold deposits of Nubia were also objectives, and in 2700 B.C., after Mernere made the first cataracts of the Nile navigable, Egyptian armies took over the Nubian gold fields, which furnished treasure to Egypt for more than two thousand

years. Thus, Egypt acquired gold, copper, and turquoise to add to her exports of glass, grain, papyrus, wool, and wine in exchange for the products of the East and West which her ruling classes required.

Metal has always tended to move east in exchange for spices, gems, silks, and other Oriental exports. As the metals of other Mediterranean countries began to augment the Egyptian supply, Egypt became the center of exchange in the western world. For ages, navigation from China or India across the Indian Ocean and up the Red Sea to Egypt was beyond nautical skill, and overland routes carried all commerce between the East and the West. As late as 325 B.C. the sea route was dangerous and difficult. Nearchus, returning with troops from Alexander's successful campaign in India, spent three months in sailing from the mouth of the Indus River to the Persian Gulf. Many of his ships were wrecked, their men lost; and numbers of his soldiers died of thirst.

There were three principal routes between India and Egypt. (See Figure 2.) The earliest route passed from the Indus River, westward along the coast bordering the Arabian Sea and the Persian Gulf, to Ur near the mouth of the Euphrates, and across Arabia to Memphis (Cairo) at the mouth of the Nile. A more northern route, which successfully competed with this one, led to the downfall of Ur and the rise of Babylon. The goods that moved north from India, or west from China, went to Bactra, just north of what is now Afghanistan, thence westward toward the south end of the Caspian Sea and southwest through Persia to Babylon. Commerce also moved along the southern coast of Persia and up the Euphrates River valley to join trade from central Asia at Babylon. From this great trade center commerce moved north and west to Tyre on the Mediterranean coast and southwest to Egypt. Babylon soon became the foremost trade center in the civilized world and the heart of one of the most stable of the ancient economic systems. Its wealth, materialism, and influence moved Jeremiah to the terse but graphic description, "Babylon hath been a golden cup in the Lord's hand, that hath made all the earth drunken." It flourished for about two thousand years; but when the Assyrians conquered Babylon about 1300 B.C., trade from central Asia was pulled northward into their country. Commerce moved from Bactra directly west to Nineveh, and Babylon no longer lay at the intersection of great trade routes. Deprived of the commerce that had nourished her, she succumbed as Ur had before her.

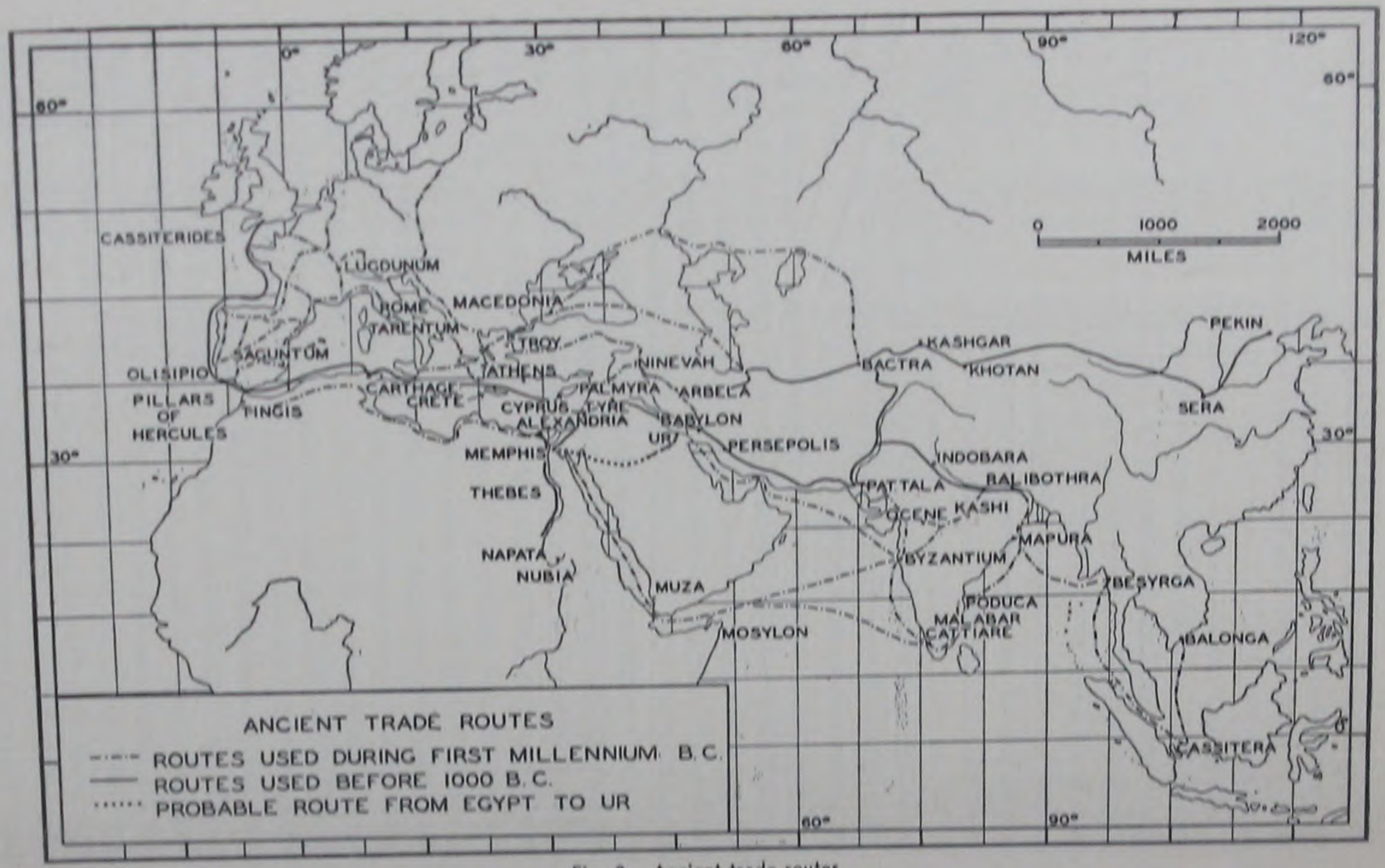

Fig. 2. Ancient trade routes.

The greater Egypt established by Mernere was unable to digest the fruits of his conquests and make permanent its recently acquired prosperity. After his death, the ambitions and intrigue of many local politicians soon disorganized the country. It was not effectively reunited until the time of Mentuhotep and Amenemhet, about 2000 B.C. The Sinai turquoise and copper deposits, the gold from Nubia and from Kush (that part of Ethiopia near the upper cataracts of the Nile), and the metal obtained from Cyprus and through trade with the Cretans contributed much wealth to the Egyptians for the next two hundred years. Again the state became disorganized; revolutions occurred; the Semitic Hyksos, employing the first horses in that part of the world, rode their cavalry through the land and conquered it. They held the territory between the Euphrates and the Nile from 1700 to 1580 B.C. The Egyptians, however, learned the arts of war from their conquerors and annihilated them in 1471 B.C., under Thothmes III.

Mining was resumed under Thothmes, and again Nubian gold, together with copper from Cypress, bolstered the power of the Pharaohs. The accumulated metal of neighboring states was an alluring objective also. About 1400 B.C. Amenhotep III sacked the country east of Egypt and returned with more than 100,000 pounds of copper, a half ton of gold, and many captives whom he used later as slaves in the Nubian gold mines. Some of the mines exploited were rich; others were of such low grade that they could not be profitably exploited today even with the most modern methods. However, the cost of metal production is largely the cost of labor; and whereas the modern miner expects to earn nearly a dollar an hour, the cost of slave labor was less than half a cent an hour in the ancient world.

Egyptian gold and copper not only supplied material for trade but also furnished the Egyptians themselves with tools for their industries, weapons for their soldiers, and the metals required for jewelry and for decoration in the palaces and tombs of the nobility. The rapid accumulation of large stocks of metals during the reign of Amenhotep III coincided with the time of Egypt's greatest power; but that period was followed by another period of anarchy. Order was restored and mining resumed by Ramses I; it was carried forward vigorously by Ramses II and probably attained its maximum production under Ramses III in the thirteenth century B.C.

According to Diodorus, the inscription under an ancient painting

of Ramses III states that his yearly revenue of gold and silver from mines was an amount that would be equivalent to 450,000 talents. Assuming that Diodorus spoke in terms of Attic weights (1 talent = 60 minas, and 1 mina = .95 pound avoirdupois), this sum is so large as to be absurd. Yet, when due allowance is made for exaggeration and for the presence of other metals alloyed with the gold and silver, the amount of metal mined by the ancient Egyptians must have been very great. Darius exacted a tribute of 700 talents of gold from Egypt annually in the early part of the sixth century B.C., an amount equivalent to about 1,500,000 dollars. This figure seems within the realm of possibility and represents a vast amount of back-breaking work on the part of unhappy mine slaves. The statement of Strabo that Ptolemy II (third century B.C.) had a revenue of 14,800 talents chiefly from his gold mines and that even Marcus Auletis (first century B.C.) obtained 12,500 talents yearly suggests that gold mines were a major factor in Egypt's history for a long period. The exact amounts represented are unknown, for in terms of either the Babylonian or ancient Greek talent these production figures would compare with the annual world output of gold a few decades ago, a most improbable yield for a period of Egyptian decadence.

At the time of Ramses II copper was mined in Sinai and iron as well as gold was obtained from Nubia. This iron was used in weapons for the Egyptian army with which Ramses II successfully fought the Hittites about 1220 B.C. After the death of Ramses III, about 1200 B.C., the growing power and despotism of the priesthood and the rigidity of their political doctrines bred discontent and revolts. At this time priests owned one-sixth of all the arable land, 169 towns, and their slaves made up 2 per cent of the population. The amount of gold, copper, and iron which they possessed is unknown but presumably amounted to a vast treasure.

The various Ramses had skimmed the cream of the mineral deposits controlled by Egypt; subsequent rulers had to be content with skimmed milk, unless they could successfully loot their neighbors. This became increasingly difficult, however, as Egyptian wealth diminished and the cost of armies drew a more and more disproportionate amount of the national income. The mineral wealth exported from the Mediterranean countries began to by-pass Egypt and to follow more northern routes to the Orient; the prosperity that walks with trade visited the countries to the north, and in them treasure accumulated. In 926 B.C., Sheshonk, a Libyan

general, who seized the Egyptian throne, raided Palestine and looted Jerusalem. He brought back, in addition to his captives, 487,000 pounds of silver and 87,000 pounds of gold. This amount of gold would have been worth more than 38,000,000 dollars in 1941, and presumably its value was greater in the tenth century B.C. Although metals were far less important to the ancient world than to our modern one, it appears that important parts of Egyptian history were shaped by the drive for their acquisition.

After the eighth century B.C., the Egyptian story is one of successive defeats. The Ethiopians conquered lower Egypt in 712 B.C.; Assyria conquered it in 673 B.C.; Persia gained it ten years later; Greece trampled it underfoot in 330 B.C., and the Romans took the country in A.D. 43. It is worthy of note that one reason for these successive invasions was the continued though diminished production of gold. As noted earlier, Darius got gold tribute from Egypt, and both Ptolemy II and Ptolemy Auletis obtained much from their mines. Subsequently Egypt was dominated by the Arabs in the seventh century, the Turks in the sixteenth century, and the British in the nineteenth century; but its production of metals has been small during this time.

Phoenicia and Mesopotamia

The wealth acquired by the early Egyptians from the copper mines of Cyprus awoke the avaricious interest of the Cretans and of the Phoenicians who lived on the Syrian coast east of Cyprus. The search for minerals led to the development of two competing nations of seafaring miners and explorers. For the first thousand years after copper was found in Cyprus, the Mediterranean trade was dominated by the early rivals of the Phoenicians, the trading freebooters of Crete. They were the first to discover the wealth hidden in the hills of Spain, Sardinia, and Elba. The Cretans not only got gold, silver, and copper from these lands, but they also took copper from Euboea and Cyprus for the Egyptians, who, though pre-eminent in many arts, were ever a nation of landlubbers. Eventually their rivals in Phoenicia and Greece found and exploited many of the sources of their raw materials and began to capture their markets. Cretan trade steadily diminished, and it sank into oblivion after the decisive defeat inflicted on them by the Greeks about 1400 B.C.

The Phoenicians searched every inlet of the Mediterranean Sea for gold, silver, copper, and tin. In their bold explorations, they

even passed Gibraltar and finally reached the south coast of England and the north coast of France. From the savages who lived in those remote wildernesses, they got tin, one of the most prized of ancient and modern strategic metals. Tin from Cornwall and Brittany and silver from Spain moved thousands of miles in their fragile galleys to the shore of the eastern Mediterranean. The sources of their metals were kept a closely guarded secret for centuries, and until the time of the Roman Empire they had a virtual monopoly on the minerals produced in what are now England and Spain. When the Greeks invested Troy, soldiers on both sides used weapons of bronze made from the tin and copper of Cornwall, which had been sold by the Phoenicians at a handsome profit. For two thousand years these sailor-miners took metal and other goods from northern Africa, southern Spain, Greece, and England to the eastern Mediterranean countries. As a result, they rose to a position of power that was out of proportion to the small size of their country. They never attempted to conquer land out of sight of the sea, however, and maritime commerce was obviously their motivating force. Much of their metal ultimately passed eastward to the Orient but paid tribute to Babylon or Assyria and to Persia and other countries for safe conduct en route. Solomon, king of the Hebrews, and his partner, Hiram of Troy, grew wealthy from their mines in Spain and the tribute paid by traffic through Jerusalem and Tyre.

With the discovery of gold to the north of Phoenicia in Lydia, northern trade routes became prosperous and more and more commerce moved toward the Black Sea region.

Nineveh was on a trade route that led through rugged Armenia from the Mediterranean to Babylon. This route was always difficult to police. The successful Assyrian kings who depended on tribute from the overland commerce, and therefore on the popularity of the road through their dominions, spent most of their time in the saddle. The discovery of metal in the Caucasus and the Ural Mountains, and the exploitation of Georgia for slaves shifted the major sources of raw materials northward. The Dardenelles became the gateway to this region and to the Orient. As traffic increased in the north, it diminished in Assyria. With steadily diminishing revenues, the problem of policing the Assyrian route became increasingly difficult. Wars were fought with the nations that were gaining wealth from the northern commerce, and eventually the stream of trade that flowed through Nineveh diminished to a trickle. The city was finally destroyed by Chaldeans, Medes,

and others about 612 B.C., but it had been the great center of exchanges for more than six centuries.

Ancient Greece

The opening of a northern trade route led to the gradual rise of Greece. Its competition with more southern routes was instrumental in bringing about a Phoenician-Assyrian alliance as early as 1200 B.C., an alliance that was broken at Troy by the Greeks under Agamemnon. During the next few centuries, a competition of rival trade routes led to successive clashes between Greeks, Assyrians, and Persians; the ultimate defeat of the Persians by the Greeks determined routes of trade for several hundred years. Mesopotamia, which existed only by virtue of its being a center of exchange, disintegrated when Themistocles conquered Xerxes in 480 B.C., a victory made possible by wealth from the newly discovered silver-lead deposits of Laurium near Athens. Part of the state revenue from the mines was diverted, at the behest of Themistocles, to build ships for a navy. At that time, a trireme or war galley, fully equipped, cost about two silver talents, equivalent to about 1,670 troy ounces, and the state's annual surplus revenue from the mines was from 50 to 100 talents. It was the custom to distribute this amount among the free citizens of Athens once a year. According to Plutarch,(7) Themistocles

> was the only man among them that durst propose that the distribution should cease, and that, with the money ships should be built to make war against the Aeginetans, who were the most flourishing people in all Greece, and by the number of their ships held the sovereignty of the sea; and Themistocles was thus the more easily able to persuade them, avoiding all mention of danger from Darius or the Persians, who were at a great distance, and their coming uncertain, and at that time not much to be feared; but by a seasonable employment of the emulation and anger felt by the Athenians against the Aeginetans, he induced them to preparation. So that with this money an hundred ships were built, with which they afterward fought with Xerxes.

According to Herodotus, the number was 180; and Diodorus states that 200 of the 317 Greek triremes in the battle of Salamis were Athenian. It was unquestionably this naval defeat that forced Xerxes to give up his conquest of Greece and saved Europe from Persian domination. The silver mines of Laurium are seldom given proper credit for the part they played in ancient history; but their importance is apparent to all who study the economic history of ancient Greece.

After the battle of Salamis in 480 B.C., Athens tried to extend

her power; but many of the competing city-states were better situated on trade routes than she and soon might have defeated her if trade had been her only source of revenue. The exploitation of the rich mines of Laurium changed the entire aspect of Athenian life and largely financed the long-drawn-out Peloponnesian wars. Athens early passed a law that provided one thousand talents of silver yearly for defense. The great wealth turned out by these state-owned mines for the next two centuries was in large measure responsible for the wealth and leisure of the Athenians. It is no mere coincidence that this was the so-called Golden Age of Greece, the high point in its development of philosophy and art. Yet the exploitation of slave labor in the mines is as black a record as can be found in the annals of any country.(8) Slaves were rented at 365 obols of silver per year, which is equivalent to 8.4 troy ounces and today would be worth about four dollars. Because of the mining conditions, the human replacements were probably about 25 per cent per year, an appalling rate which corresponds with the reputation for inhumanity that the Laurium leasors possessed throughout antiquity. With the gradual exhaustion of its mines, the power of Athens disappeared.

Shortly after the discovery of lead-silver ore near Athens, gold was found in northern Greece on the slopes of Mount Pangaeus in Macedonia. The local rulers became wealthy as these deposits were exploited, and Philip, the father of Alexander the Great, drew an average income of 1,000 gold talents per year from his Macedonian mines. As an Attic talent was about 60 pounds troy, a talent represented about 25,000 dollars in gold at its 1940 value of 35 dollars an ounce. During Alexander's brief life, these mines produced more than 30,000 talents, the equivalent of 750,000,000 dollars. This treasure bought the equipment and financed his first campaign, but tribute from conquered nations probably proved ample to finance his later military adventures.

Alexander's major aim was to concentrate the five existing routes to the Orient in a single economic system; loot was a secondary but important consideration. With this in mind, he crushed the Phoenicians at Tyre, took over the lower Nile and established Alexandria, and moved northeast to Thapsacus on the Euphrates River in search of the Persian Army. Before Alexander finally caught up with Darius III and defeated him at Arbela, this parsimonious Persian found time to bury a treasure that contained among other things more than fifteen tons of gold bullion which Darius always kept

with him under special guard during a military campaign. For centuries after, expeditions were outfitted in Greece and Rome to search for the buried treasure; but so far as is known, none were successful. With the defeat of the Persians at Arbela, Alexander gained control of the three economic systems that furnished the greatest competition to Greece. From Arbela, he moved southeast to Persepolis in Persia, then north and east to Bactra, where he spent the winter of 328 B.C. From here he moved south through India and west to Babylon and thus finally consolidated the five separate economies within one empire. (See Figure 2.)

The men who won their livelihood from the stony soil and mineralized rocks of ancient Greece were inventive, intelligent, and aggressive but notably lacking in the quality of sustained co-operation. The environment did not lend itself to the development of agriculture, nor were the people inclined toward manufacturing. Except for their temporary coalescence under Alexander, the Greeks throughout their history showed a remarkable genius for disunity and interstate bickering. It is not surprising that Greece was unable to find men with sufficient integrity and executive ability to hold together the empire that the rare talent of Alexander had built.

The Roman Empire

Like the Greeks, the Romans were good soldiers, inventive, but uninterested in agriculture and manufacture. Unlike the Greeks, the Romans were born administrators and highly co-operative. At the beginning of their rise to power they had no help from mineral wealth such as had favored the Greeks. The treasure the Romans obtained by plundering Tarentum in 269 B.C. enabled them to invest in a military machine. Their combined army and navy returned rich dividends in loot from Greece, Carthage, and Gaul. Marc Antony reminded his audience that Caesar "brought many captives home to Rome whose ransoms the general coffers filled." But when all the countries accessible to Rome had come under her control, she had to stop plundering and form an empire dependent on commerce, with Rome as its imperial commercial capital.

Much of Rome's success was due to her fortunate geographic position with respect to Mediterranean trade routes, which converge naturally on Italy. After the empire was established, the military took over all mines in tributary countries. It was thus that they were able to pay for administration and policing of distant territory. During the three centuries that Rome occupied what is now Spain,

her mines yielded an average of more than 300,000 ounces of gold (105,000,000 dollars) annually to the conqueror, and, in addition, much iron, copper, silver, and mercury. With the gradual exhaustion of ore, the supply of metal for export diminished, the purchasing power of Rome fell correspondingly, trade with the Orient declined, and the military machine became weak and inefficient. It is interesting to note that Pliny bewailed the flow of metal to the East but suggested no solution to this problem.

Dependence on plunder instead of on creation of wealth through manufactures and agriculture produces a parasitic economy that destroys both its host and itself. As early as A.D. 9, the lethal effects of Rome's economic policy began to appear. Augustus could not replace the army of Varus which was destroyed by the Germans in that year, although at this time there was in Rome gold and silver to the value of 358,000,000 pounds sterling, about sixteen times the amount that was present in A.D. 800. The proportion of precious metal in the coinage was gradually decreased; by A.D. 220, silver was so scarce that the debased currency could not be sustained and the government repudiated its debts. The natural consequence was loss of trade and lack of funds for upkeep of the government and the military. The consequent economic collapse and disintegration of the Roman system into separate states was due only in part to war and barbarian conquest. Although the causes of Rome's decline were complex, the exhaustion of mineral resources was an important factor.

The Dark Ages

With the fall of the Roman Empire, three peoples took over the control of the highways to the East—the Persians, the Byzantines on the Bosphorus, and the Saracens on the Nile. Interchange of goods between East and West continued, but the West had comparatively little to offer. The metals of Europe, which were coveted by the East, seemed to be mined out. The "Dark Ages" descended upon Europe, lasting from the advent of Alaric in A.D. 410 to the time of Charlemagne.

Navigation from India directly across the Indian Ocean to the Red Sea had been first tried in the time of the Caesars; but during the Dark Ages this route was far less popular than the one through the Persian Gulf to the mouth of the Euphrates River. Nearly all the diminished traffic from the Orient passed overland through Bactra or up the Euphrates valley through Bagdad, which became

one of the great trade centers of the world. The very name, Bagdad, is synonymous with luxury, power, and magnificent display. During the seventh and eighth centuries, the followers of Mohammed, the Arabian merchant-prophet, spread their conquests through Arabia, western Asia, and northern Africa and made Bagdad their capital. For a time, this entire region was controlled by the Caliph of Bagdad; but as the commercial interests of the different parts of the Caliphate came into conflict with one another, it broke into independent units. In the tenth century, the Fatimid Turks established a separate Mohammedan empire in Egypt and the lands bordering the Red Sea and the western Mediterranean Sea. The dominions of the Fatimid Turks straddled the Red Sea route, and commerce was soon persuaded to make increased use of this route. At first nearly all the Indian trade that did not move through Bactra went by way of the Euphrates valley; but within a short time, more merchants were paying tribute to the Caliph of Cairo than to the Caliph of Bagdad.

Brooks Adams(1) ascribes the popularity of the Indian Ocean-Red Sea route in the ninth century to the introduction of the compass. Traders, however, for centuries had known and used the monsoon winds without a compass for the journey from southern India to the Red Sea. It is more probable that the amount of traffic moving over the different trade routes reflected the relative safety of merchandise shipped over them. A long period of civil wars began in northwestern India about the tenth century; petty kingdoms fought with one another, and political instability was the rule. Continuing conditions of this sort anywhere on a great trade route would hurt the whole system and, even though localized only at certain vital places, might ruin it. Merchants of the spice trade, like their modern brothers, were concerned with the arrival of their goods at the places to which they were consigned. As a natural consequence, the commerce through northwestern India and Bactra dwindled during the troublous days this region experienced at the end of the first millennium A.D. The unpopularity of the Indian Ocean-Red Sea route after the fall of the Roman Empire was due more to the pirates who swarmed along the coast of southern Arabia than to the lack of a mariner's compass. The use of this southern route increased rapidly when the entire region fell under the sway of powerful rulers interested in taxes rather than loot. Tribute they demanded of travelers, but in return they provided an increasing measure of safety. When, coupled with this assurance of safe

conduct, the cost of moving goods over the Red Sea route became less than that of freighting through Bagdad, its success was certain.

Transportation directly across the Indian Ocean and up the Red Sea to Egypt was also quicker than the old caravan route through Bagdad or that still farther north through Bactra to Constantinople (Istanbul). Central Asia and Mesopotamia became eccentric to the flow of commerce between the Orient and the West, and as a result their wealth and power steadily diminished. This shift in the trade routes led to the rapid rise of Egypt, which was then in the hands of the Fatimid Turks or Saracens, as the Mohammedan people of the eastern Mediterranean countries were generally called in Europe. The establishment of a Fatimid empire coincided with the decline in prestige of Constantinople and Bagdad.

As most of the mines of Rome lay near the poorly protected borders of her empire, little effort was made to continue their operation once production began to fall off. During the Dark Ages, a little gold was washed from the sands of the Rhone, Danube, Tiber, and Po rivers, but the gold and silver mines of Spain, which had supplied so much metal in the past, were closed by the Visigoths. Mining was not resumed until near the close of the eighth century when Charlemagne began to open up deposits in central Europe. Lead, silver, and gold were taken from mines at Rothansberg, Kremnitz and Schemnitz by enslaved captives and contributed substantially to his revenue.

Europe between A.D. 800 and 1800

Emergence from the Dark Ages coincided with the discovery and development of mineral deposits in Germany, Bohemia, the Harz, and Tyrol. The Rammelsburg silver deposits found in 920 furnished Henry the Fowler with money to fortify the Harz, provided a large part of the funds for both Henry and his son Otto the Great in their military campaigns, and helped to finance the development of an empire. As the meager stream of metal that characterized the Dark Ages of Europe increased in volume, commerce with China, the Spice Islands, and India increased in proportion, and nearly all paid tribute to the rulers of Egypt. The Caliphs of Cairo, and later the Sultans, taxed traffic to a point just short of where it would have been more profitable to use the overland route through Bagdad and Constantinople.

Metal from central Europe moved directly south to Venice at the head of the Adriatic Sea. From a poverty-stricken fishing village

in the ninth century, Venice rapidly grew into the richest port in southern Europe. She retained this position till Vasco de Gama opened the sea route around Africa to India and China in 1498. The power of the Saracens in this period is suggested by the unsuccessful Christian Crusades against them; the weakness of Constantinople, by the ease with which it was sacked. The looting of the city and the massacre of the men, women, and children within its gates was perpetrated by the impoverished Crusaders of Pope Innocent in 1204, in spite of his unqualified disapproval. The enterprise was frankly undertaken to obtain sufficient booty to satisfy the debt owed to Venice for their transportation. Similarly, the strength of central European powers, rich in newly developed mineral deposits, is shown by their successful defeat of the Mongols, who ravaged all the countries to the east and overran those to the south as far as the borders of Egypt.

German and Venetian vessels met at Flanders. As sea rates cheapened, the inland highways, whose cost was higher, lost importance, and centers of exchange moved to the ports of western Europe. The competition of rivers and related seaways with land-borne transportation was felt severely by France in the period from 1000 to 1450 and was a major economic cause of the wars between France and Flanders and France and England.

The heavy tolls collected on traffic through Egypt and Arabia by the Turks was a thorn in the flesh of Christian merchants trading with the Orient. Decreasing cost of ocean-borne freight and increasing speed and safety of this mode of transportation stimulated search for an ocean route between the East and the West. Success was finally achieved when Vasco da Gama returned from the Indies in 1499 with a cargo of spices. The fortunes of Spain and Portugal rose like a skyrocket for a brief and eventful period. The price of spices brought over the new sea route netted a large profit at less than half the cost of delivery by the old route to Venice. When da Gama's third fleet returned in 1502 and disposed of its 5,250,000-dollar cargo, Venice and those countries depending on trade passing through Egypt all faced ruin. The successful competition of the new trade route led to war as a natural consequence; but the military strength of the Marmadukes, a mixed race of Turk and Tartar who then controlled the eastern Mediterranean country, lay on land rather than on sea. The Portuguese defeated the Saracen fleet in the Arabian Sea in 1509, effectively closing the Indian Ocean-Red Sea route. This action not only cut off Egypt but also

made Venice eccentric to eastern trade. The power of Venice was destroyed.

Even before da Gama discovered a sea route to the Indies, the tide of commerce had begun to ebb in Venice. Although this ebbing was caused chiefly by the gradual diminution in output from the mines of central Europe during the latter part of the fifteenth century, the city was also feeling the competition of river routes with Alpine highways. The rich lead-silver deposits of Freiberg, Saxony, were discovered in 1170; those of Joachimsthal, in Silesia, about 1200; and the deposits at Schneeburg, in 1460. After 1200, more and more metal from these deposits moved down the Rhine to the Netherlands. It is interesting to note that the Freiberg deposits were found by drivers of salt carts en route between Halle and Bohemia. Just prior to 1500, Venice found herself suffering from an annual adverse balance of trade that amounted to more than 300,000 ducats ($1,050,000). This adverse balance was covered by exports of a corresponding amount of gold bullion, which had to be withdrawn from the hoard accumulated previously. The gradual decline in European metal production brought with it the threat of a return to the Dark Ages. The threat might have been realized had not new sources of mineral wealth been found in central Europe and, a little later, in Mexico and South America.

The river systems inside Europe often competed with one another. Thus, the Rhine and Main were in direct competition with the Rhone and Seine, and the efforts of Charles the Fifth to consolidate this system were foredoomed to failure. The fortunate position of the Netherlands with respect to both sea and river transportation systems led the most important trade routes of Europe to converge here. Antwerp soon took its place as the financial center of the world. Coal, zinc, lead, and iron mines were found near by in Belgium and western Germany. The zinc-smelting industry of Europe centered here, and even in 1939, long after the mines had been exhausted, many smelters, using imported ore, still were in operation.

Charles the Fifth went deeply into debt to obtain his crown and become head of the Holy Roman Empire. This debt was the beginning of a continually increasing financial burden, for Charles required large revenues to maintain his army, navy, and government officials. With treasure coming from America and the profits of the spice trade, Spain and Portugal could have become wealthy. However, Italy yielded only a small income; France with its com-

peting and unsuccessful economy, and Spain with its military burden, asked more than they paid in taxes. The chief support of all the Holy Roman Empire was soon placed on the Netherlands and the New World. This burden led to revolt in the Netherlands; its bloody suppression by d'Alva forced the emigration of many energetic and skilled artisans across the Channel to the great benefit of England.

The movement of metal from the New World did not reach large proportions until nearly 1570, about the time that England's policy of "hijacking" the Spanish plunder of Mexico was becoming successful. The seizure of treasure from America by Drake and other privateers had much to do with forcing the suspension of pay to the Spanish army, the chief factor in its mutiny, and was thus the underlying economic cause that led ultimately to the sack of Antwerp in 1576. A substantial part of the money used by Queen Elizabeth in the construction of the navy that defeated the Spaniards came from the gold and silver taken from Spanish galleons while en route from Mexico to Spain. With the defeat of the Armada in 1588, Spain's brief period of power was over. England and the Netherlands rose in fortune as they developed their domestic mineral resources and those of their colonies, took over the great trade route established by the Spanish, and founded the East India Company and the Dutch East India Company at the beginning of the seventeenth century.

Queen Elizabeth forbade the use of certain forests for charcoal, the only fuel then used for smelting, in order to conserve timber for building ships. Her highhanded edict stimulated the use of coal and ultimately led to the use of coke in the blast furnace, the key to rapid large-scale smelting of iron. This advance in metallurgy came at a fortunate time for England and the Netherlands. Their happy position as the center of exchanges in regions having coal and other mineral resources resulted in the rapid industrialization of both countries. (See Chapter 3.)

The unfavorable location of France with respect to trade routes and mineral resources led her to make repeated efforts to obtain control of them through war. These economic factors have directed French policy for centuries and, incidentally, explain her action during the Thirty Years' War. Germany, possessed of mineral wealth and dominating the north countries through the activity of the Hanseatic League, was becoming a dangerously powerful commercial and military power. The avarice of Hanseatic merchants caused

much friction, especially in Sweden, where a valuable mineral industry had started up. The exploitation of her silver, copper, and iron mines, about 1600, coincided with an increase in the energy of the whole country. The revenues derived from Swedish mineral deposits helped finance the Thirty Years' War and the invasion of Germany in 1630 by Gustavus Adolphus. However, the cost of fighting so strong an adversary was beyond his purse, and he appealed to France for help. Cardinal Richelieu achieved one of the best examples of Machiavellian logic when, after having tens of thousands of Huguenots killed presumably because of their Protestant religion, he financed the Lutheran Swede in order to destroy the Roman Catholic Hapsburgs whose dominion threatened the economic security of France. The Treaty of Westphalia, signed in 1648, cut Germany into more than three hundred independent states, principalities, and free towns. Such a dismembered nation was no longer a threat to France, and for two hundred years the Germans offered little challenge to the nations competing for European leadership. Under Frederick the Great, many of the states in the northern and northeastern part of what later became Germany coalesced in the middle of the eighteenth century; but the area included in his kingdom was small compared to the Germany of 1875.

The same economic factors that governed the policy of Richelieu underlay the war between France and Holland in 1672–1678. Following the Dutch victory, French competition with England and Holland became less and less successful. After the British began to utilize coke to smelt iron about 1730, their iron and steel industry forged rapidly ahead. By 1770, England had achieved world supremacy in the production of steel and a concomitant position of financial power; but France had become practically insolvent. Her unsuccessful wars and her incompetent, extravagant monarchs had caused such a chaotic economy that the French Revolution was a natural consequence.

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CHAPTER 4

The Industrial Era

Foreword

THROUGHOUT the Industrial Era, parallel conditions and events have been repeated in various countries so often that a definite pattern seems discernable. The curves representing the statistical history of many phases of our industrial activity have a remarkably similar form. The typical shape of such a change-with-time curve is that of a slanting attenuated S. (See Figure 3.) This seems to be the general pattern of the Industrial Era.

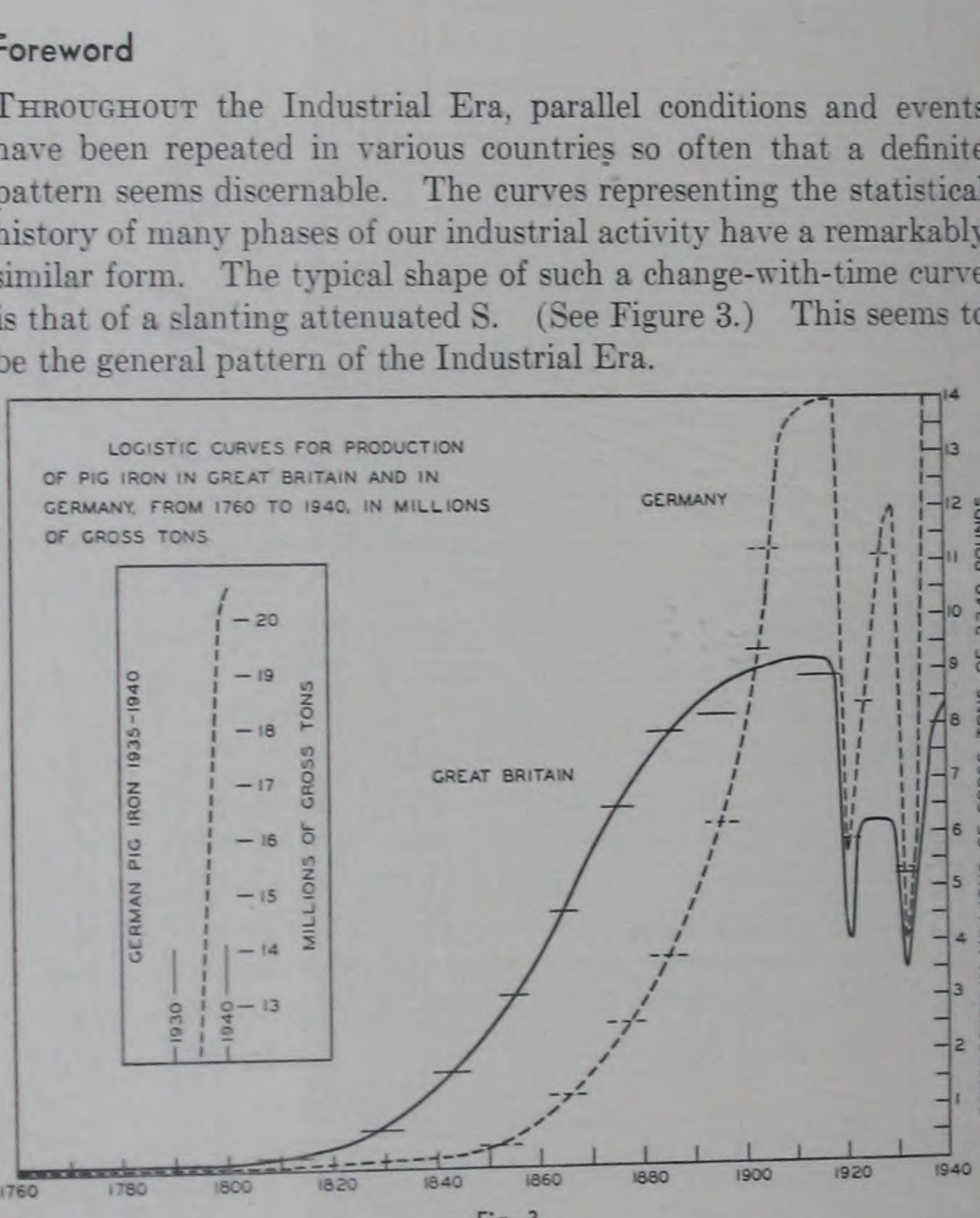


Fig. 3.

Whenever new conditions are imposed on a responsive medium and maintained, changes tending toward a new equilibrium take place. Slow at first, the adjustment proceeds with increasing speed

and, after achieving a maximum rate, gradually tapers off and finally ceases when a new equilibrium is attained. Curves showing such changes belong to the class called logistic curves. Logistic graphs express many kinds of biological, physical, and chemical phenomena. The studies of Pearl(7) brought out the remarkable precision with which mathematical logistic curves fitted a wide variety of biologic phenomena. Even more remarkable is the similarity of change-with-time curves representing unrelated subjects and conditions. The temperature rise in a cool body that is suddenly placed in warm surroundings, multiplication of yeast cells in a given medium, growth of population, urbanization of various countries, attainment of equilibrium between reacting chemicals, and demand for metals all fit the pattern of these S-shaped logistic curves.

The simple S-shaped curves hold only when new conditions which disturbed the former equilibrium are maintained essentially constant until equilibrium is reached. The form of the curve will be modified if additional disturbing factors affect the responding material from time to time.

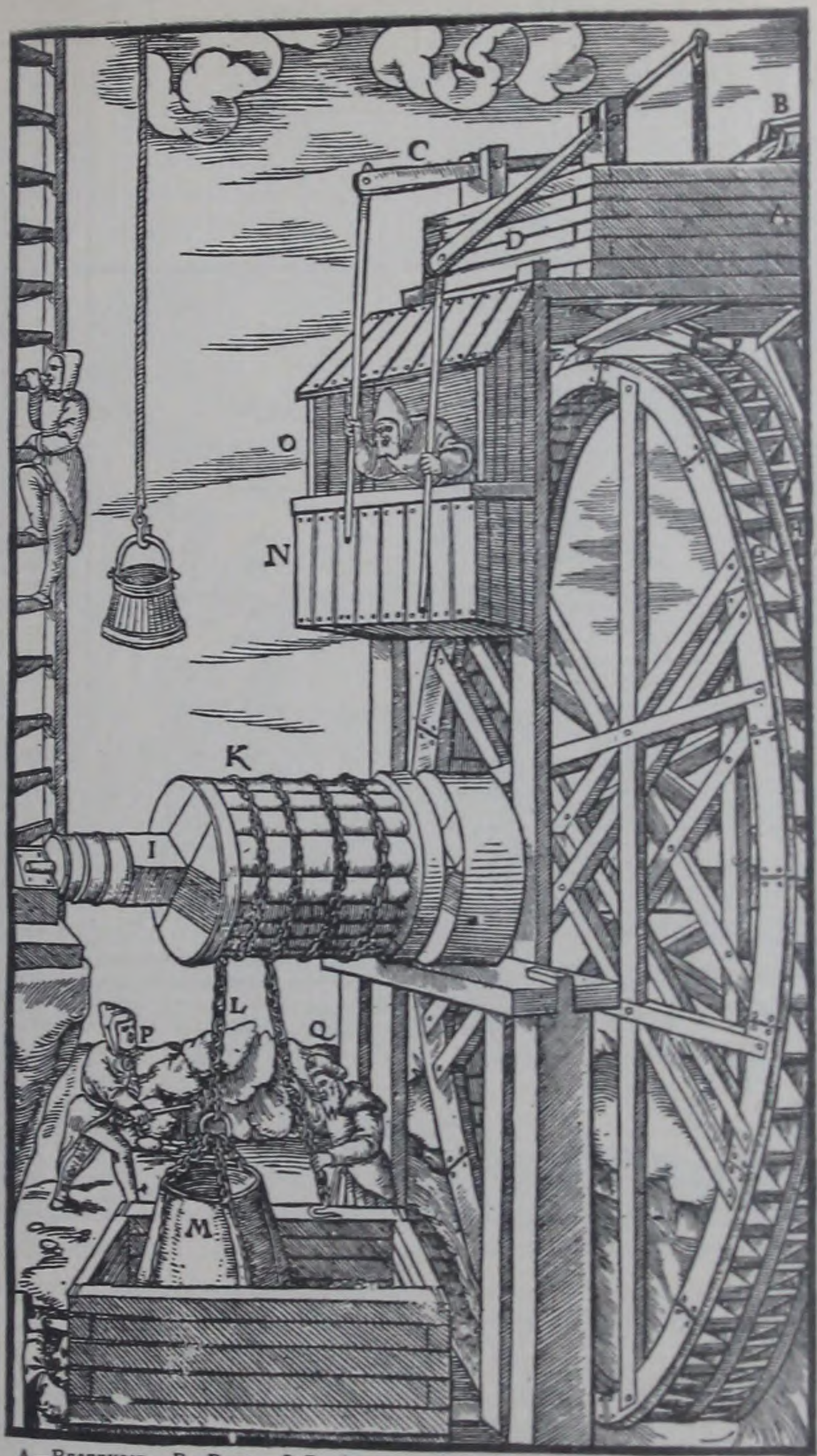
When machine civilization begins to transform a vegetable culture, it imposes dynamic new conditions that affect every activity of the people. At the beginning of the Industrial era, huge new markets and a multiplication of inventions caused a rapid rise in logistic curves depicting the demand for metals and the prosperity of manufacturing nations. Unfortunately, however, depletion of mineral resources and increasing competition made possible by foreign deposits imposed new and adverse conditions on the social and economic structure of various countries, resulting in a reversal of the rising curve. Unhappy readjustments became necessary as the social and political structure moved toward equilibrium with the new adverse factors. The various countries of Europe began industrialization at different times. Comparable stages were drawn out to more than a century in some and telescoped to a few decades in others. Britain, Belgium, and the United States are among the fortunate few that enjoyed a period of increasing prosperity through nearly a hundred years.

It will be the purpose of the following pages to note some of the dynamic conditions new to the agricultural civilization of eighteenth-century Europe, to discuss their impact upon various peoples, and to suggest some of the causes that delayed the response of certain countries long after others were making revolutionary readjustments.

Pre-railway Europe

James Watt invented the steam engine in 1768 and opened the door to the Industrial era. Some fifty years earlier, Abraham Darby, a British Quaker of Coalbrookdale in Shropshire, developed the technique of using coke for smelting iron and made possible the production of high-grade cheap iron in quantity. Iron masters and miners were among the first to take advantage of the power furnished by Watt's invention. Steam hoists soon replaced laborious and inefficient methods of hoisting rock previously employed, such as that shown in Figure 4. At the turn of the century, the famous Cornish pumps were making great new stores of ore available throughout the British mining districts. Hundreds of mines with good ore still present in the bottom levels had been abandoned because of heavy flows of underground water. A study of the multitudinous devices used to persuade water out of a mine in the sixteenth century compels admiration and sympathy for the clever miners who struggled with this ubiquitous problem of the industry. (See Figure 5.)

With the advent of a powerful steam pump, Britain's flooded mines were reopened, quickly unwatered, and good ore was mined to depths undreamed of a generation earlier. Steam-powered "blowing engines" were used for blast furnaces. The combination of steam power and England's fine coking coals so increased the output of British iron that shortly before 1800 she wrested the leadership from Sweden, the foremost producer of charcoal iron. At that time, the world's output of pig iron was only 540,000 tons, and of this total Great Britain produced 35 per cent, Sweden 30 per cent, and Russia 20 per cent. Since inventions multiply in regions where special needs and problems stimulate thought and action, it is not surprising that nearly all of the major developments in the art of making iron and steel during the nineteenth century originated in Great Britain. It was but natural that these inventions should be most quickly appreciated in England and that their effects should be soonest apparent here. The invention of the spinning jenny in 1815 multiplied the effectiveness of an individual spinner two hundred times. Other labor-saving devices soon followed, and the transformation of England from an agricultural country to a manufacturing nation progressed rapidly. The transformation is attested by the change in the urban population. In 1800, nearly 78 per cent of the population was rural; but in 1850, the rural and urban popu-



A—Reservoir. B—Race. C, D—Levers. E, F—Troughs under the water gates. G, H—Double rows of buckets. I—Axle. K—Larger drum. L—Drawing-chain. M—Bag. N—Hanging cage. O—Man who directs the machine. P, Q—Men emptying bags.

Fig. 4. The inefficient but ingenious sixteenth-century predecessor of a steam hoist. From Agricola's "De Re Metallica," Hoover Translation, 1910.

lations were almost equally balanced. In 1881, less than 40 per cent of the population lived in the country.(6, p. 445; 11, p. 24)

On the continent, the conditions of the eighteenth century lingered on for decades. At the beginning of the nineteenth century, 90 per cent of all Europeans outside of Italy and England lived in

A—Axle. B—Drum. C—Drawing-chain. D—Balls. E—Clamps.

Fig. 5. How a mine was unwatered before the Cornish pump was invented. From Agricola's "De Re Metallica," Hoover Translation, 1910.

the country. Delay in the industrialization of central Europe is emphasized by the figures for rural and urban population in Germany. In 1800, only 10 per cent of the population lived in cities and towns of more than 2,500 people; and even seventy-five years later the proportion of city dwellers had increased to only 36 per cent.

A century and a half ago land transportation was exceedingly

primitive. Horse-drawn vehicles moved through stifling clouds of dust in dry weather or wallowed through heavy mud in the wet season. Freighting costs were high, except by boat, and even waterborne freight was expensive on many routes, for inland waterways as well as roads were burdened with many toll stops. Easy access to maritime shipping was at that time essential to the industrial development of any region. The growth of railways during the eighteen-thirties and eighteen-forties imposed an entirely new condition on Europe's economic system. For the first time, cheap transportation in all weather became available to inland settlements.

Great Britain

The industrial revolution made coal and iron the most valuable mineral resources a country could have within its borders. England was fortunate in possessing large deposits of these minerals and, in addition, rich ores of copper, tin, lead, and zinc. The exploitation of these deposits by modern methods greatly strengthened her economic position. In the nineteenth century, Great Britain was successively the world's largest producer of lead, copper, tin, iron, and coal. During that period she was the wealthiest nation in the world. She supplied more than half the world's demand for some of these metals. From 1700 to 1850, the United Kingdom mined over 50 per cent of the world's lead; from 1820 to 1840, she produced 45 per cent of the world's copper; from 1850 to 1890, she increased her iron production from one-third to one-half of the entire world output. It is interesting to note that this rapid exploitation of mineral reserves led to peak production for each of the minerals, followed by the inevitable decline that must be expected to accompany increasing costs with depth and by gradual exhaustion of the mineral deposits. The peak was reached for lead in 1856, for copper in 1863, for tin in 1871, for iron ore in 1882, and for coal in 1913.(1)

The industrial hegemony of Great Britain during the nineteenth century was due to the happy juxtaposition of coal, iron, cheap skilled labor, and cheap transportation to the great world markets. The island kingdom was far more fortunately situated with respect to transportation than were most European countries. In addition to her great merchant fleet, the United Kingdom led all the nations of Europe in mileage of railroad for many decades. It was not until about 1875 that Germany caught up to her. (See Table II.)

The figures of this table tell a significant story. In 1840, there were 840 miles of railroad in the United Kingdom, 360 miles in

TABLE II

Mileage of Railroads*

	1840	*1850*	*1860*	*1870*	*1880*	*1888*	*1935*	*Area (square miles)*
United Kingdom	838	6,620	10,430	15,540	17,930	19,810	20,419	94,284
France	360	1,890	5,880	9,770	14,500	20,900	26,076	212,659
Germany	341	3,640	6,980	11,730	20,690	24,270	33,431	186,714
Russia	16	310	990	7,100	14,020	17,700	52,040	8,144,228
Belgium	210	550	1,070	1,800	2,400	2,760	3,102	11,752
Austria	90	960	2,810	5,950	11,500	15,610	—	—
Italy	13	270	1,120	3,830	5,340	7,830	14,305	119,744
United States	2,820	9,020	30,630	53,400	93,670	156,080	241,822	3,026,789
Canada	16	70	2,090	2,500	6,890	12,700	38,556	3,694,863
Japan	—	—	—	—	75	910	13,734	148,756

* Data from Mulhall's *Dictionary of Statistics* and from the *New York World-Telegram's World Almanac.*

France, 341 miles in Germany, and 210 miles in Belgium. In 1860, the United Kingdom had increased its mileage to 6,620, while France and Germany claimed only 1,890 and 3,640 miles respectively; the United States led the world, then as now.

England's economy was based primarily on manufacturing and trade during most of the nineteenth century. Not only did her textile manufacturers have access to all of her colonial markets, but her growing manufacturing industry and the movement of workers into the cities created an immense internal market for machinery and the building trades. As her industrial plants began to reach equilibrium as a result of conditions arising out of the railroad age, foreign markets took an increasing proportion of British-made machinery. Building slackened, however, and the vigorous growth of her internal market ceased. The demands of potential competitors who were clamoring for machines and material for a time took the place formerly held by the expanding internal market.

It is interesting to note that the total value of England's imports and exports has shown a continuously increasing adverse balance of trade since 1854, the year when the statistical abstracts of the Board of Trade began to appear. This has been true even for her colonial trade since about 1860. However, since British citizens controlled most of the import and export trade of dominions, colonies, and of the British Isles, a substantial amount of the fund credited to colonial exports was in reality a payment to citizens of Great Britain.

Although Canada achieved tariff autonomy in 1859 and Australia was granted a similar measure of independence even earlier, the Crown retained a decisive influence in the government and the formulation of policy in both colonies and dominions throughout the nineteenth century. In spite of being the world's foremost advocate of free trade, Britain found many ways to "discourage" foreign commercial enterprise. The record indicates the effectiveness of these ways. Britain's colonial policy, in common with that of other European nations, tended to check the building of factories in the colonies. In Mulhall's *Dictionary of Statistics* at the close of the century, only raw materials appear on the list of exports from Britain's colonies. These raw materials were sold to British exporters in the colonies, shipped to England, fabricated, and reshipped to the colonies and other markets through British importers in the various countries. The successful exploitation of other than her mineral resources is naïvely suggested by Mulhall (6, p. 365):

> The following examples show the economy of labor resulting from machinery. . . . A girl twelve years old in a Lancashire mill can turn out thirty-five yards of printed calico daily, the work in one year sufficing to clothe yearly 1,200 persons in the East.

As England became more and more industrialized, the boats that took her manufactured goods to agricultural countries came back laden with foodstuffs. These agricultural imports could easily undersell food produced on England's high-priced land. Where formerly the profits made on the sale of merchandise returned in considerable part to the British agriculturists, a substantial part now flowed back across the sea, and the great land-holding class in England gradually became impoverished.

By the latter part of the nineteenth century, the investments in new British industrial plants were falling off while an increasing demand for mineral raw materials was stimulating even greater interest in mines. Much British capital was invested in mining districts at home, and large sums were spent in the mineralized frontier countries of the world, especially in British colonies. Of the 222,000,000 pounds sterling of capital authorized for new companies registered in 1889, banks claimed 57,200,000, mines 37,000,000, and manufactures only 21,800,000. The value of minerals produced in the United Kingdom in 1888 amounted to about 185,000,000 pounds sterling, only a fifth of the value of the manufactures; yet the new investments showed a ratio of nearly two to one in favor of mining as compared with manufacturing enterprises. Britain had reached her peak in domestic mineral production, except in coal, and one of the factors in her commercial greatness had changed. She no longer had an abundance of cheaply mined high-grade ore close to manufacturing centers; and concomitant with increasing cost of mineral production, German, French, and American competition made itself felt in foreign markets.

An industrial economy runs most smoothly when the value of export trade exceeds that of imports by only a small margin. Too large a "favorable" trade balance can be as unfortunate as an adverse trade balance, a truth that the United States discovered to its sorrow in the nineteen-thirties. If wealth is being created by building, mining, or other forms of improvement that increase a nation's collateral, it may withstand an adverse trade balance indefinitely. However, when this yearly increase in collateral diminishes or ceases, it is essential that the adverse balance of trade also diminish or cease. Great Britain with her large colonial empire had oppor-

tunities for reinvestment of capital that enabled her to support the apparent trade debit much longer than she would have been able to do if she had lacked these assets.

Thus we find British capital acquiring tin properties in Malaya; gold, lead, and tin in Australia; iron in Spain, and a substantial part of the varied natural resources of the United States and other countries. Where such countries were politically weak, as in South Africa, the commercial penetration that accompanied the discovery of mineral wealth was followed by the flag. The successful conquest of the Boer republics gave Great Britain the richest gold-producing area the world has ever known; and as the wealth derived from more than half the world's annual gold production flowed into her coffers, British strength increased again.

Central Europe

The social and economic conditions that existed in England during the eighteenth century held over for nearly a hundred years in central Europe. In the early part of the nineteenth century, the continent was torn by the Napoleonic wars, and France threatened to reduce Prussia and the other countries of central Europe to the condition of vassal states. Strangely enough, after Prussia and her allies finally defeated the French armies, France was left almost intact. Instead of carving the country into a number of independent but impotent minor states, the "balance of power" principle, probably first formulated at Münster, Westphalia in 1648, was written into the Treaty of Vienna in 1815 and, together with "legitimacy"—the recognition of the rights of pre-revolution sovereigns—in a large measure determined the territorial settlements. The Germanic confederation that was created served as a buffer to hold France and Russia in check. It was assumed that politically powerful Austria would be leader of the new confederation and would dictate policies. This the Dual Monarchy did for a time with confidence and success, but the era of Metternich waned as the forces of the Industrial era began to galvanize the Germanies. The strength of the amalgamating German states grew slowly for a time, but with Bismarck's defeat of Austria in 1866 the way was cleared for a phenomenally rapid rise in power. If it were possible to plot a logistic graph showing the growth of German industrial and political power, the Peace of Prague in 1866 would be plotted at the place where it showed the first sharp upward inflection. Not only was the long duel with Austria settled definitely, but Prussian

domination was soon extended to include the North German States, and the way was clear for southward and westward expansion. For the first time since the Treaty of Westphalia, it became possible to organize a powerful Teutonic commercial nation.

Prior to 1815 the German people lived in scores of small principalities which strove jealously against one another in an essentially feudal agricultural society. At this time all Europe seemed satisfied to sit back and continue its vegetable culture. Central Europe was held in bondage by poor communications, provincialism, selfishness, lack of co-operation, and illiteracy. Serfdom was widespread, except in Austria and west of the Weser River. Frontiers were only a few miles apart, roads were poor, and toll gates were frequent even along waterways, the easy highways for commerce provided by nature. On the Weser River between Minden and Elsfleth, a distance of only a hundred miles, a boat had to pass through eight separate political entities and pay toll at thirty-two stops. The markets were chiefly internal, supported by small communities. Foreign markets at this time were held almost entirely by the British and Dutch, and the people of central Europe were apparently willing to go on forever as a rural population.

Mining went forward in many places, but tariffs and bans limited sales. Because of the large amount required, salt was one of the most valuable mineral products and was mined at many places. When Schonebach and Halle became part of Prussia in 1820, an edict was issued forbidding the importation of salt so that Halle might supply the entire demand of Prussia. Iron, silver, copper, and some tin were mined in a small way here and there in the highlands of south and central Germany. The iron ores of the Harz Mountains and those near Freiberg and Bayreuth supported small enterprises of local importance only. Charcoal was used for smelting and the iron industry was thus forest-centered. Except in Belgium, the Netherlands, and adjacent parts of France, iron and steel making were carried on much as they had been for centuries.

In accordance with the principles laid down by the Treaty of Vienna, Prussia's boundaries were redrawn in 1815 to include the Rhineland and dozens of principalities along the Moselle, Ruhr, and Sieg rivers; they were also extended to the east and north, since England believed that a strong Prussia would do much to prevent a recurrence of the devastating wars that had harassed the continent. The reborn Prussia more than fulfilled expectations and soon grew to be one of the strongest powers in Europe. It took

the first step in this direction in 1818 when it formed a customs union that ultimately led to the Zollverein, which by 1837 included nearly all of the Germanic states except Austria. The members of this loose coalition gradually eliminated nearly all the tariff barriers between and within them. Prior to 1850 there had been no fewer than sixty tariffs within Prussia alone. Bismarck's shrewd combination of political and military pressure brought more and more territory under Prussian domination, the process of acquisition culminating in the brief Franco-Prussian war in 1870, the annexation of Alsace-Lorraine in 1871, and the absorption of the South German states.

Germany was late in her industrial awakening, but adequate transportation facilities began to take form soon after the Germanic Confederation was set up by the Congress of Vienna. Engineers attacked natural obstructions to the waterways, opening channels through rocky shoals, as at Bingen, and the state gradually eliminated such artificial barriers as obstructive tolls and tariffs. Canals were extended, harbor facilities were improved, and relatively cheap transportation became possible between towns and cities on inland waterways and the coast.

It was not until after railroads appeared, about 1840, that Germany's heavy industries commenced to grow apace. Between 1800 and 1840, her annual coal production increased from 300,000 tons to 3,400,000 tons, corresponding to an increased share in the world's total from 2.6 per cent to 7.6 per cent. During the next few years the annual output mounted to 59,100,000 tons, or 17.5 per cent of the world's total.(6, p. 119) The statistics on iron production tell a similar story.(6, p. 332) In 1800 Germany produced 40,000 tons, 8.7 per cent of the world total. By 1840 her output had risen to 170,000 tons, 6.8 per cent of the world's increased production; but in 1880 she began to register a gain in the proportion of the world output that, though small, was significant. In that year German ironmasters poured 730,000 tons of pig iron, 6.9 per cent of the world production; and less than a decade later she was making 18 per cent of the world's pig iron.

In contrast to British coal fields, which were making Britain the greatest political and commercial power in the world, German coal fields lay fallow during the early part of the nineteenth century. It was not until 1840 that the Prussians began to exploit Ruhr coal seriously. Iron ore from the near-by East Rhine districts, such as Siegerland and Bergischer Kalkberg, at first supplied the raw mate-

rial for Germany's budding iron and steel industry. Krupp, the Andrew Carnegie of Germany, was one of the first to grasp the industrial potentalities of the Ruhr district and was not without appreciation of the military market supported by the competing European nations. The great armament and steel works at Essen soon became one of the largest in the world. By 1876 Krupp had delivered 15,000 cannon to various nations, and his plant consumed more than 500 tons of steel a day.

Before 1840 European railroads were scattered local affairs that linked near-by cities in much the same way as do modern interurban trolleys. Their rapid growth during the next few decades provided a ready market for iron and steel, and they in turn provided ever cheaper access to raw materials and to markets for finished products. By 1870 many of the Great Powers had extensive rail networks; nevertheless, an increasing amount of export coal, iron, and steel moved to the coast by way of the now easily navigable inland waterways.

Germany's iron resources were still quite adequate to her needs when she acquired the Alsace-Lorraine deposits in 1871. It was not the tremendous reserve of low-grade iron ore that inspired Bismarck to move Germany's boundaries westward; rather it was the well-developed cotton textile industry of these German-speaking pro-French provinces and Bismarck's desire to dominate the classic routes of French invasion. At that time, most of the iron ores were of little worth because of their high phosphorus content; but within a few years the Thomas process had made them suitable food for the voracious appetite of Germany's rapidly growing iron industry, and these ores are now one of the most valuable assets in Europe. Thus, the latter half of the nineteenth century found central Europe with a well-developed transportation system, a skilled industrial population, plentiful supplies of excellent steam and coking coal, a huge reserve of satisfactory iron ore close to adequate transportation, all within a region where the artificial barriers caused by political boundaries had been eliminated. With the road thus cleared, German manufacturing forged ahead rapidly. The industrial development was reflected by the amazing growth of the industrial cities. (See Table III.)(11, pp. 132–135) The figures for Essen, which is in the heart of the Ruhr area, are especially significant.

Germany entered the industrial race two generations after England. Even in 1870 Germany was an essentially agricultural coun-

TABLE III

POPULATION GROWTH IN SOME GERMAN INDUSTRIAL CITIES

	1800	*1850*	*1880*	*1920*	*1935*
Berlin	172,000	419,000	1,122,000	—	4,232,500
Cologne	50,000	97,000	145,000	634,000	756,600
Munich	30,000	110,000	230,000	631,000	735,388
Schemnitz	14,000	32,000	95,000	304,000	350,734
Dusseldorf	10,000	27,000	35,000	407,000	498,600
Essen	4,000	9,000	57,000	439,000	654,451

try with only 36 per cent of her population living in towns; but during the next thirty years the proportion rose to 60 per cent. The exchange of coke and iron ore between the Alsace-Lorraine deposits and the Ruhr valley assumed major proportions in the eighties and nineties. During this period iron ore moved into Germany in some localities and out of it in others. It was not until 1898 that the imports exceeded the exports. From that time on Germany never again achieved self-sufficiency in this all-important raw material.

The steady expansion of Germany's heavy industries from 1870 to 1914 reflected the increasing market for German manufactures. While rapid urbanization was taking place, the domestic market took a substantial proportion of the local output; but the proportion of manufactured goods absorbed by the internal market shrank as the movement of workers from country to city slowed down. As Germany came of age industrially, she became less a customer and more a competitor of Great Britain and other industrial nations. From 1854 to 1880 Germany was one of the most profitable outlets for Great Britain's manufactures; in this period the United Kingdom had a far more favorable balance of trade with Germany than with any other country. The surplus value of exports to Germany over imports for this period amounted to 240,000,000 pounds sterling, an average of about 9,000,000 pounds per year. In the eighties the favorable balance dropped to half this figure, and the total value of goods exported annually to Germany dropped from about 34,000,000 pounds to 25,000,000 pounds.

At the turn of the century Germany was the third largest coal producer in the world and was exporting increasing amounts in competition with Great Britain. She was essentially self-sufficient in iron ore, produced more zinc than any other nation in the world, possessed a world monopoly on potash, and was one of the leading producers of salt. During the next fourteen years Germany im-

ported an increasing amount of iron ore, and in 1913 she required 11,400,000 tons of foreign ore to augment her domestic production of 28,600,000 tons of low-grade ore. Although Germany's zinc production increased steadily during this period, more and more of it came from imported ore. Domestic production of zinc ore reached a peak in 1905 when 731,000 tons were mined. Even at this time, 87,000 tons of foreign ore supplemented domestic production, and by 1914 net imports had increased to about 270,000 tons and domestic production had dropped to 646,000 tons.

In the decade preceding the first world war Germany and Great Britain were in similar stages of development. The change-with-time curves representing their industrial growth had flattened, and competition between the two nations was increasingly bitter. Foreign markets were sought for German goods and German capitalists looked about for foreign investments. In all the areas controlled by the great colonial empires of France, Belgium, Holland, and England, the commerce and capital of the mother country were favored and both German capital and German commerce found themselves in an inferior competitive position. Nearly all of the regions of the world that contained "backward" people who could be dominated or protected by European nations had already been made part of colonial empires of other nations. Germany's own colonies proved rather unprofitable and showed no promise of sustaining the trade of the Fatherland in the way that British, Dutch, and Belgian colonies held up the commerce and finance of Great Britain, Holland, and Belgium. Thus, Germany at the eve of the first world war was an industrially powerful nation, dissatisfied with its territorial assets, competing aggressively with Belgium, France, England, and the United States and irritated by its lack of "a place in the sun."

France and Belgium

The economic history of Belgium parallels that of England, although the industrial plant and commerce were on a smaller scale. Belgium was only a pale shadow of her imperialistic big brother across the channel. The output of iron increased from 62,000 tons in 1854 to 523,000 tons in 1870, the year when Belgium first began to make steel in appreciable quantities. Although the iron output leveled off at about 500,000 tons for the next few decades, her steel production increased from 4,000 tons in 1870 to 216,000 tons in 1887. During the eighteen-nineties the production of both iron and steel

mounted rapidly and in 1900 was well over a million tons. By 1913 nearly all the pig iron produced was being converted into steel, and steel was being produced at the rate of 2,500,000 tons annually. Belgium first began importing iron ore about 1860, and from that time on her increasing output of iron and steel depended more and more on imported ores. The art of smelting zinc developed in Belgium, but her zinc mines were exhausted early and her smelters have been fed on imported ores for a century. Much of Belgium's wealth grew from her favorable position with respect to transportation routes, the skill of her mechanics, and the shrewdness of her traders in world markets. Unlike Holland, her colonies supplied almost no outlet. It was not until the twentieth century that the great mineral wealth of her African empire materially augmented her revenues.

Throughout the first seventy years of the nineteenth century the rate of industrial growth of France was intermediate between that of Germany and England. She was set back by the loss of Alsace-Lorraine, however, and Germany soon moved ahead of her. France maintained a net favorable balance of trade until 1870 and then showed an increasingly unfavorable net balance. The trade with her colonies was always favorable to her and they were her largest market as well as her chief source of raw materials. Most of the vital factors in French economic history during the Industrial era have already been touched upon in the discussion of Germany and Great Britain. The French pattern was similar to the British, but France lacked the extensive coal fields of her neighbors to the east, north, and west. Although she lost a large potential source of iron ore to Germany in 1871, the region in France next to Alsace-Lorraine contained the southwestern extension of the great beds of ore, although at such a depth they were believed unusable when the treaty of Frankfurt am Main was signed that year. After the Thomas process made the phosphatic Lorraine ore workable, the French sank shafts on their side of the boundary and opened up the same ore beds exploited at the surface to the northeast by the Germans.

Each succeeding year saw a larger tonnage of French ore raised, and in 1912 more ore was mined in northern France than in Alsace-Lorraine.

Russia and Austria-Hungary

Both Russia and Austria-Hungary were polyglot nations consisting of numerous ethnic subdivisions held together by despotic gov-

ernments. Both nations remained agricultural throughout the nineteenth century. The mineral resources of Austria-Hungary were small and but meagerly exploited. Even as late as 1913, Austria-Hungary produced only one-fourth as much pig iron as did little Belgium. At this time her total coal production was nearly twice that of Belgium, but two-thirds of the coal was lignitic.

Transportation has always been one of Russia's major problems because of the vast distances in her great expanse of forest and plain. Long before the Czar had thought of a trans-Siberian railway, an east-west transcontinental road was used by daring travelers winter and summer. Raphael Pumpelly, an American geologist, graphically describes a long but interesting trip across Siberia by sleigh in the winter of 1862.(8) The three-thousand mile trip from Irkutsk to Novgorod consumed only twenty-three days and the Czars' couriers often made it in fifteen days.

The Soviet Union's great river systems are natural arteries of commerce and were exploited at an early date. The Volga and Don rivers were connected by canals about the beginning of the nineteenth century, and with the opening of the Vishney Canal in 1825, a waterway 1,434 miles long became available from St. Petersburg to the Caspian Sea. In 1886 there were nearly 34,000 miles of navigable waterways in Russia.(6, p. 104) However, even as late as 1887 there were but 17,700 miles of railroads, in contrast to the 156,000 miles that existed in the United States at the same time.

For centuries inland traffic paid heavy tolls to foreign nations before it reached the sea. The two major ambitions of Peter the Great were to unify Russia and to obtain salt-water ports. The founding of St. Petersburg (Leningrad), in 1721, brought realization of the latter ambition. Throughout the eighteenth and most of the nineteenth century, however, a sand bar across the mouth of the River Neva prevented freighters from reaching the docks, and goods had to be loaded into barges at Kronstadt and reshipped. Until the Poutiloff Canal was opened in 1884, more time was usually required for goods to move the fifteen miles from Kronstadt to St. Petersburg than from Liverpool to Kronstadt.

The long struggle between Russia and Turkey in southern Europe was dictated in considerable measure by the same desire for access to maritime trade as had led to conquest of the Baltic provinces.

The great mineral resources of Russia were developed slowly in the nineteenth century. As in most of Europe during the Agricultural era, Russia contained many different iron-making centers.

Russian iron was favorably known in the seventeenth and eighteenth centuries and was an important export from the districts in the south lying between the Black Sea and the Ural Mountains. Many districts in the southern Ural Mountains, as well as more distant ones in the Altai and Nertschensk Mountains, contributed to the river trade in summer and the sledge-borne freight of winter. In 1828 a total of 900 furnaces were known to be at work in Perm, Vialka, and Nijni, and it is estimated that Russia produced approximately 115,000 tons of iron that year. Production rose to 220,000 tons in 1850, to 600,000 tons in 1888, to 2,700,000 tons in 1900, and by 1913 reached 4,557,000 tons of pig iron and 4,837,000 tons of steel; figures that were not equaled again until 1930.(6; 3; 5)

Russia's locomotives and boats were fired by wood from her immense forests until well into the twentieth century, and her coal production was insignificant until after the eighteen-eighties. By 1900 she was producing 16,000,000 tons of coal, or about two-thirds as much as Belgium produced during the same year. She doubled this figure by 1913 and stood where Great Britain had stood seventy years earlier. However, prior to the first world war, most of her other diverse mineral resources were little exploited, except for gold and petroleum, both of which accounted for a substantial amount of the world's total. For a brief time at the turn of the century, Russia was the leading producer of petroleum in the world. Before the discovery of the South African gold fields, Russia was the world's foremost gold producer; and during the eighteen-eighties, when the annual world output was about 5,000,000 ounces, Russia exceeded the United States, her nearest competitor, by approximately 250,000 ounces per annum.

The United States

Until the thirteen colonies broke away from Great Britain, the balance of trade was always favorable to the mother country. Although politically independent after 1776, the United States remained in the economic position of a British colony for the next two generations. It manufactured but little and most of its fabricated goods were imported from England. Not until 1840 was the United States able to balance her imports and her exports, but from that time on she consistently enjoyed a favorable trade balance not only with England but with most of the leading industrial nations of the world.

Iron workers emigrated to the American colonies as early as

1620 and began to practice their trade here; but they were dependent upon imported iron for their raw material. The first American furnace was established in 1663 at Lynn, Massachusetts, by Joseph Jenks, and iron smelting commenced. As the colonial iron industry expanded, imports from England fell off, and in 1750 the British Parliament passed a law to close all the mills and furnaces in the colonies in order to protect British manufacturers. After the War for Independence the amount of pig iron produced in the United States began to show substantial gains. The increase from 40,000 tons in 1800 to 550,000 tons in 1850 suggests the slow but steady growth of iron-making while it was dependent on the scattered mediocre eastern deposits.

Until late in the eighteen-forties mineral production in the United States was small. The annual production of gold was less than 500,000 dollars per year until after 1847. As part of the fruits of the Mexican conquest, the United States acquired California in 1848 only a few days before the discovery of gold in this territory at Sutter's sawmill. The gold rush of '49 brought a wave of eager prospectors into the unknown country between the Mississippi and the Pacific. Within a few hectic decades the virgin metal deposits of the West were opened to a metal-hungry world. The annual gold output of the United States soon increased a hundredfold. The value of the gold washed from California's gravels during 1848 amounted to 10,000,000 dollars; in 1850 it had increased to 50,000,000 dollars. The great quantity of precious metal mined each year excited millions of people, led to the rapid exploration and settlement of all the western country, and entirely changed the financial situation of the United States. The rich new mineral resources created a large purchasing power for the exploiters, and development of the West provided an expanding internal market that accelerated industrialization of those eastern states in which coal and iron were cheaply accessible.

With the opening of the St. Mary's River Canal at Sault Sainte Marie in 1855, the richest and largest iron ore bodies known became cheaply accessible to Pennsylvania coal and coke. A rapidly mounting production for both iron and steel was the natural consequence. In 1860 the United States produced 1,670,000 tons of iron, or 28 per cent of Britain's production for the same year, but within two decades she overtook and surpassed her rival. In the latter part of the ensuing decade, the United States also displaced Great Britain as the world's premier producer of coal. Thus in

1900 Great Britain gave place to the United States as the world's foremost producer of the two minerals most essential to our industrial economy.

Throughout the nineteenth century the United States was a haven for European immigrants. Settling these peoples in the communities that were constantly springing up required boats, railroads, buildings, and roads. The growing American market at first belonged to the British; but as the coal and iron resources of the United States came into their own, they supplied more and more adequately the needs of the internal market and began to serve foreign markets as well. The internal trade of the United States has always exceeded her foreign commerce by fifteen or twenty times, but by 1913 the United States claimed 12 per cent of the world's foreign trade. Fortunately for the manufacturing industry of the United States and of the world, the automobile market opened up as the railroad boom declined. Here, too, the United States led all other countries in production and consumption.

The machine age has created wealth through the extraction of raw materials from the ground and has multiplied this wealth through the skillful fabrication of raw material into the multitude of articles demanded by our Industrial era. As the United States possesses within its borders nearly all of the materials required by industry, each year found it trading larger quantities of useful goods and machines for gold or for an increasing commercial control over resources in other countries. On the eve of the first world war the change-with-time curve representing the industrial growth of the United States was still rising rapidly. The citizens of this country enjoyed the highest standard of living in the world, and our financiers competed on an equal footing with those of any nation.

Power politics

It has already been noted that the principle of power politics, or "the balance of power" among European nations, was recognized in the covenant of the Treaty of Vienna in 1815. Throughout the nineteenth century various Great Powers appealed to this principle to prevent conflict. Their appeals, however, were not always successful, as witness the Franco-Prussian War; but at other times it worked to the satisfaction of the major powers. After the Russo-Turkish conflict, when the avarice of the Czar threatened to set a world conflagration, or at least a European war comparable to those engineered by Napoleon, Bismarck in 1878 persuaded the great

powers of Europe to meet and "arbitrate" their differences. The principles of the Concert of Europe were invoked. Russia had defeated Turkey and had made a treaty that pushed her sphere of influence southwest to the Dardanelles and the Bosphorus. Such an extension of power was felt to be inimical to the interests of Great Britain, Austria-Hungary, and France. At Bismarck's suggestion, a series of "horse trades" were made at the expense of such weak nations as Turkey, Rumania, and the other Balkan states, which were required to give up much, to the benefit of the Great Powers, in return for little from them. Russia was given Kars, Batum, and Bessarabia; Austria obtained Bosnia and Herzegovina; Germany obtained prestige; Great Britain got Cyprus; and a little later France was given Tunisia. A general European conflict was thus averted. During the next few decades the lines of cleavage between the various European countries became more definite. The nations sought alliances with countries whose interests conflicted least with their own. The belief in mutual protection against competing or avaricious neighbors, as well as the desire to have strength for aggression themselves, resulted in the triple alliance of Germany, Austria-Hungary, and Italy. This group opposed France and England on one side and Russia on the other.

The Balkan wars of 1912 and 1913 greatly increased the power of the twice-victorious Serbs. In 1914 it was clearly apparent that the Serbs intended to unite the southern Slavs of the Danube basin, absorb Bosnia, Herzegovina, Croatia, Slavonia, and Dalmatia, with Russia's blessing on the enterprise. Rumania regarded Transylvania, Bucovina, and the Banat hungrily, and the Czechs were restless. The ethnic divisions of the Dual Monarchy were eager to become independent political entities, and it seemed unlikely that the Austrian Empire could suffer the threatened internal struggle without crumbling. Clearly the dissolution of Austria-Hungary would shift the balance of power away from Germany's hands.

In August, 1914, Germany moved to save her chief ally, forestalling probable Russian expansion and hoping that she, instead of England, would emerge holding the balance of power and a substantial amount of new territory. That she failed is due largely to the adroitness of the British and the clumsiness of the Germans in handling their American relations and to the ever-deeper involvements of the United States as purveyor to the war market of the Allies. By the spring of 1916 it became clear to the government

of the United States that our interests were tied so tightly to the fortunes of the Allies that a German victory would be a commercial catastrophe for the people of the United States. Although financial and political considerations may have been uppermost in the minds of our political leaders, the average American citizen welcomed the declaration of war in 1917 because of his natural sympathy for the underdog, his belief in the atrocity stories, and a somewhat one-sided presentation of the British and German naval policies with respect to neutral ships carrying munitions to the belligerents.(2)

November, 1918, found bitterly hostile and fear-ridden statesmen in a position to dictate terms of peace to our exhausted opponents. The cardinal principle of Wilson's famous Fourteen Points was self-determination for the ethnic minorities of Europe in any peace settlement. This the American public believed would be the only basis of a just and lasting peace, one that would "make the world safe for Democracy." However, it was plainly apparent that if this principle were put into practice Germany would emerge with more territory and industrial power than she possessed in 1914, if the 75,000,000 German-speaking people of central Europe constituted themselves as a single state. The loss to Germany of the German-speaking provinces of Alsace-Lorraine was specified in the Fourteen Points, but the territory of Austria would more than equal that loss and the loss along the Polish border. Although the transfer of the heavy industries of Alsace-Lorraine to France would be a hard blow, it could be accepted cheerfully if traded for the rich city of Vienna and the industrial plant of all Austria. Little would be lost to Poland, as the valuable mines, metallurgical works, and factories of Silesia were nearly all in German-speaking territory.(12) Such a situation was, of course, unthinkable and it became necessary to scuttle the Fourteen Point program in favor of a more realistic approach to the problem of so weakening Germany that she would no longer be a threat to the Allies.

The Treaty of Versailles to a large extent abandoned Wilson's principle of self-determination for the peoples of Europe and redrew the boundaries on strategic rather than ethnic grounds.

Although the Treaty of Versailles has been criticized as having been too harsh, its chief aim was to destroy the power of Germany and to augment that of Great Britain and France. This it accomplished. To continue to be effective it was necessary that the victorious nations collaborate and that their pledges to one another

be scrupulously fulfilled. The statesmen of the Allies failed to meet these necessary conditions. As in the past, expediency rather than ethics guided the ships of state.

When the final peace settlements were completed, the former Dual Monarchy had lost more than 68 per cent of its territory and 58 per cent of its population. It lost nearly all of its gold, silver, copper, and mercury deposits, 80 per cent of its forests, 60 per cent of its vineyards, 80 per cent of its coal mines, 80 per cent of its iron-producing capacity, 75 per cent of its glass works, 75 per cent of its pastures, and 67 per cent of its famous flax land. Czechoslovakia received much of the mineral land, Rumania was given agricultural land, and Yugoslavia obtained a substantial proportion of both. Italy acquired the great mercury deposits of Idria. Hungary and Austria were reduced to agricultural states largely dependent on such exports as wheat, lard, flour, poultry, feathers, hides, and animals. The only developed mineral assets left to Hungary were a few iron mines and some low-grade coal deposits; but her large unexploited bauxite beds became an important source of revenue a decade later. Austria was a little better off; it contained, in addition to low-grade coal and an iron mine, a number of deposits of nonmetallic minerals such as magnesite, gypsum, salt, talc, graphite, and china clay, as well as mediocre lead, zinc, silver, copper, mercury, and antimony ores. It is a significant commentary on the industrial plants left these countries that during the nineteen-twenties both exported iron and steel, though Austria poured only 1,000,000 tons of pig iron annually and Hungary about a third as much. (3; 4; 5; 10; 12)

Only two-thirds of Czechoslovakia's 15,000,000 people were Czechs. Her boundaries were drawn on lines of industrial efficiency and military strategy, not on ethnic divisions. Czechoslovakia possessed 11,000 factories which included machine, metal, furniture, and shoe factories, chemical plants, glass works, and textile and paper mills. She was given the excellent coal fields of Most, Chomutov, Teplice, Moravská Ostrava, and Falknov. In addition, she had copper and manganese in Slovakia, silver in Bohemia, and iron-mining districts west of Košice and west of Prague. The Košice deposit was of special interest because of the occurrence of a mercury-bearing mineral (tetrahedrite) from which some mercury was recovered each year.

Rumania played a highly intelligent part in the first world war. She declared war on the Central Powers in 1916 and the country

was immediately occupied by the Germans who forced King Ferdinand to sign the Treaty of Bucharest. Two days before the armistice in 1918, however, this treaty was repudiated and war again declared. Rumania was rewarded by territory from Austria-Hungary, Bulgaria, and the Soviet Union, which more than doubled her size. The population of the enlarged state was about 19,000,000 and contained approximately 3,500,000 alien people. Rumania retained her oil fields but got little new mineral land and remained an essentially agricultural state. The fertile lands of Bessarabia, Transylvania, Bukovina, and part of Banat added enormously to her agricultural wealth and belie the statement sometimes made that no country won anything from the first world war.

The territory given to Yugoslavia had a population of 14,000,000 of which approximately 7,500,000 were Serbs, 3,500,000 Croats, 1,000,000 were Slovenes and the remainder was made up of Germans, Hungarians, Albanians, and Rumanians. This polyglot state had the most richly mineralized territory in southeastern Europe. The new Yugoslavia possessed great deposits of bauxite along the Dalmatian coast, large deposits of zinc in Ljubljana, the largest deposits of copper in Europe outside of the Soviet Union, some good iron deposits, but unfortunately only brown coal. She also had important deposits of antimony, chromite, lead, magnetite, pyrite, and salt which were brought into production during the next ten years. Her mineral wealth was but little developed when her boundaries were set in 1919, but it was known to exist and was soon actively exploited by British, French, American, and German, as well as Yugoslav capital. Although the coal resources were unsatisfactory, Yugoslavia possessed 3,000,000 horsepower in hydroelectric power, 20 per cent more than that of Switzerland but with only about 10 per cent as much horsepower developed. This territory obviously contained many raw materials in which Germany was short, and by 1935 Germany had become Yugoslavia's largest customer as well as her chief source of imports for finished goods and high-grade coal.

Germany lost an area of 28,000 square miles and a population of 7,000,000 inhabitants of whom only 42 per cent spoke the German language. One industrial unit after another was cut by new boundaries. The largest amount of German territory went to Poland. The south boundary of Poland disrupted the Silesian economic unit, and the Polish Corridor severed east Prussia from the rest of Germany. The loss of rich agricultural, forest, and mineral land

and the great industrial center of Posen was a severe blow to Germany and did nothing to increase her love for the Poles. Alsace-Lorraine and its iron ores were returned to France, and once again a boundary line cut through the natural economic unit containing the Ruhr coal and the Lorraine iron ore. With Alsace went the great potash deposits near Mulhouse in southern Alsace, which were the basis for such diverse chemical industries as the manufacture of soaps, matches, explosives, chemicals, dyes, and fertilizers.

The readjustments that followed the territorial and industrial dislocations practically wiped out Germany's large middle class, and a greatly decreased standard of living was the natural consequence of the ruthless treatment that followed the war. The food blockade was maintained for nearly a year after the Armistice and was largely responsible for the social and political unrest that in 1922 officially expressed itself in the fall of Wirth, first chancellor of the Weimar Republic and the man who accepted the conditions of the Versailles Treaty. During this unhappy period, several million Germans, chiefly old men and women and the youngest children, died of starvation, and according to the statistics of accredited physicians 90 per cent of the school children were undernourished. The occupation of the Ruhr by French troops in 1923 and the harsh treatment of the people when Germany failed to deliver its full reparations quota of telegraph poles, timber, and coal unified the Germans in much the same way that Pearl Harbor brought the American people together twenty years later. German nationalism was reborn during this period and a Hitler became possible.

The growth of French influence in the Near East and the sympathy of the French masses for the Soviet Union experiment was viewed with apprehension by the conservative Tory and the almost equally conservative Labor parties which ruled England by turns. The British upper classes at this time were convinced that French influence must be weakened in order to maintain the balance of power. They had become more sympathetic with Germany's economic plight than with French fears, and they set about strengthening the recent enemy.

A period of comparative tranquility was ushered in by the Treaty of Locarno, in 1924, which brought Germany into the League of Nations, moved the French army out of the Ruhr, and pledged the British to defend Germany against France, or France and Belgium against Germany if any of these countries should seek to change the status quo. Germany on her part reaffirmed her agreement to

demilitarize the Rhineland and to accept the Alsace-Lorraine boundaries as they had been determined at Versailles as well as her mutual boundaries with Austria, Czechoslovakia, and Poland. During the next few years Germany moved rapidly forward under Stresemann's able leadership. German factories competed successfully with those of other countries, and the standard of living of the German masses rose slowly but continuously. To be sure, the cost of raw materials obtained from foreign sources might have been slightly higher in Germany than in England or the United States, but German labor and technical skill absorbed this handicap without too much difficulty so long as there were extensive markets for her products. However, two catastrophes—the death of Stresemann and the start of the great depression—overtook Germany in 1929. During the brief period of progress before this date, the German people had had almost complete relief from the financial burden of supporting a military machine. American loans largely had paid the reparations of Germany and thus indirectly built the great Maginot line on the French frontier. The competing industrial nations suffered from financial burdens not felt in Germany that tended to offset any advantage they might have had in access to raw materials.

The economic collapse of the early nineteen-thirties found Germany with a weak internal market and no adequate financial reserve to carry her through the depression. The desperate efforts of all the industrial nations to protect their own internal markets from foreign competition led to a wave of economic nationalism, started perhaps by the Smoot-Hawley bill of the United States. By this time, both Germany and England were dependent upon outside trade for their maintenance. England could use her colonies, but Germany had no such prop. The millions of unemployed in Germany presented a hopeless problem to their government in 1930 and 1931. The standard of living plunged; as more people became hungry, bitterness and resentment flared up, and Germany was ready for Hitler. He promised and gave them work, food, radios, prestige, and a feeling of importance. In return for this bowl of pottage, all he required was that the German people give up freedom. The hordes of unemployed were being fed somehow; it was only sensible to make them work for their subsistence since, as Brooks Adams pointed out long ago, the sum normally paid for labor is only a subsistence wage. When these millions were set to work in munition factories and on the farm, Germany's productive

capacity increased by nearly 50 per cent. A substantial part of this labor was utilized in producing the most modern war machinery that could be devised, although this was in direct violation of treaties with France and England.

When German rearmament began in 1933, the British Minister of War announced that Great Britain would oppose strongly any German attempt to rearm in violation of the Versailles Treaty. In December of the same year, however, Hitler was conceded almost everything that he demanded, on the grounds that rearmament had already been accomplished and unless war were risked nothing could be done about it. This tacit approval of the British to the building of a German military force created deep antagonism among the French and strained Anglo-French relations severely. The British and French estrangement, which became apparent in 1933 when His Majesty's government acquiesced in the creation of Hitler's new army, was emphasized again in 1935 when Great Britain concluded a separate treaty with Germany allowing her to build a navy up to 35 per cent of Britain's strength and to violate the air treaty pact. All of these agreements were directly contrary to the Versailles Treaty and to French interests.

When Hitler moved his troops into the Rhineland and abrogated the Locarno Treaty in 1936, France called upon Britain to fulfill her pledges; but Great Britain refused because by that time Germany was partly rearmed and to fulfill the pledge might mean war. Thus, when the event took place for which the treaty was designed, Great Britain repudiated her agreement. Unfortunately, this action was characteristic of British policy during the nineteen-thirties. When Japan invaded China in 1931, China appealed to the League of Nations for protection against the aggressor nation; the United States at the same time invoked the Nine Power Treaty to prevent aggression, but Sir John Simon told the United States bluntly that Britain would remain neutral. After several days of hearings at the League of Nations, Sir John defended the Japanese course of action, and Matsuoka, whose implacable hatred of Britain and America was later to cost both nations thousands upon thousands of lives, told the correspondents with satisfaction that Sir John Simon had told the League of Nations in half an hour what he had been trying to tell it for weeks. Thus, Great Britain, through being instrumental in preventing the League from imposing sanctions, discredited the whole mechanism set up for collective security at this time.

The deep-seated fear of communism held by the British ruling classes made it seem highly desirable to balance the growing power of the Soviet Union by a strong Germany which would also serve as a threat to the trend toward socialism in both France and Spain. The rift created in Anglo-French relations was paralleled by a growing lack of sympathy between the United States and Great Britain. The rubber cartel, the tin cartel, the repudiation of war debts, and the proposed alliance of British and German businessmen who had similar interests in South American trade, in opposition to United States interests, as late as 1939 did little to promote good feeling between the two countries.

It is interesting to contrast the policies dictated by the small clique that ruled England with the will of the majority. In 1935, when Italy began her adventure in Abyssinia, the British government, as represented at that time by Simon and Baldwin, did nothing to hinder this outright aggression of a powerful modern military machine against a comparatively helpless people. It was not until after the famous British Peace Ballot on June 27, 1935—bitterly opposed by the government—that action was forced. When 11,500,000 people vote in a country whose total population is but 46,000,000, it takes no Dr. Gallup to interpret the will of the majority. The score stood 11,000,000 to 500,000 to remain in the League of Nations; more than 10,000,000 voted for economic sanctions against Italy and 6,000,000 voted for and 2,000,000 against military sanctions. With general elections coming on in the fall, some kind of action clearly had to be taken. The government voted to boycott such things as Italian marble and sulphur, and placed economic sanctions on many articles not essential to the conduct of the war. However, when Italy warned that sanctions on oil would be regarded as an act of war between Great Britain and herself, British officials allowed the Anglo-Iranian Oil Company and the Shell Oil Company to supply the Italian army with oil throughout its campaign. As the British government owned stock in both companies, Italian war planes were fueled with oil sold by the officially protesting government. However, the imposition of economic sanctions of any sort was a triumph for the average British citizen, and the party was re-elected with an overwhelming majority in the fall. In Paris a month later Sir Samuel Hoare and Pierre Laval tried to conduct the familiar power-politics horse-trade with Italy, but both public opinion and the power of the average citizen had changed during the years, and procedure that had been condoned

with satisfaction a few decades earlier aroused a storm of protest. Sir Samuel was forced to resign as the scapegoat, but in a short time Great Britain accepted all the Italian claims for the conquest of Abyssinia.

By the end of the nineteen-thirties, both the British people and their government began to fear German military might much more than they feared any Red menace. The product of total employment in German and Italian factories and munition plants was now definitely weighing down the Axis side of the European balance-of-power seesaw, to the disadvantage of France and England. The sudden movement of the Soviet Union to the middle of the plank in August, 1939, raised France and England helplessly high in the air with no stepladder handy. It has been said that the people of England forced their government to declare war on Germany. It might be more proper to say that the people's sense of outrage at Nazi treatment of minorities, indignation at the vacillating appeasement and repudiation program of their government, and a tardy recognition at Number 10 Downing Street that *Mein Kampf* was a blueprint and not a fairy tale made both rulers and ruled ready for war. After the invasion of Czechoslovakia in the fall of 1938 all Britain knew that war was coming. On September 2, 1939, less than a year later, the British government felt it necessary to announce in a world-wide broadcast that "if Germany successfully invades Poland she destroys the balance of power which His Majesty's government has sought to preserve for more than a century; this is a condition that Great Britain cannot tolerate."

The immediate causes of the second world war were clearly psychological and political; but the immediate causes grew out of social conditions, and the social conditions in turn were profoundly affected by the distribution and control of raw materials.

Minerals and the causes of conflict

Much has been said in the past to the effect that raw materials are an immediate cause of war. The eagerness of deficient nations for rich mineral deposits has undoubtedly been a major factor in some imperialistic wars between industrial countries and relatively helpless neighbors. The aquisitive spirit of a few powerful political and industrial leaders was a potent factor in bringing on the first and second world wars, but the mass discontent that breeds the spirit of conflict is generally due to profound economic dislocations. Because of the shortcomings of our present economic system, min-

eral deficiencies enter as an important ultimate cause of war. This fact may be due in considerable part to short-sighted policies of nations endowed with mineral wealth.

In all countries the continual struggle for power by individuals results in two conflicting political tendencies: 1) to delegate more authority to a centralized government; 2) opposing this, to increase the power of those controlling the individual political subdivisions of the nation. In the United States this is the familiar conflict between the extension of federal authority and that of States' Rights. The ever-shifting map of Europe reflects a similar struggle through the centuries. Whenever minor political entities have forgotten their differences and coalesced to form larger units, certain economic advantages accrue but certain disadvantages are also entailed. The economic benefits of union have already been pointed out (see page 66). The administration of many different ethnic groups is difficult at best, and commonly in Europe there has been a marked discrimination against certain minorities or groups by those in power. National policies are designed to insure security, prosperity, prestige, or unification. However, this latter aim might be regarded as a necessary step in achieving the other three. Both the populace and the rulers are most closely concerned with the security, prosperity, and prestige of the individual. Among rulers these three desires are reflected by national policies and among the people in their day-to-day contacts with one another.

Some wars of the past could be carried on by volunteer armies and navies without affecting the daily life of the great mass of the citizenry. The directors of a nation's destiny could engage in such military adventures with far less regard for the opinions of the people than is possible when millions of conscripts are requisitioned and all phases of industrial activity are affected.

It has become increasingly necessary to "propagandize" the citizens of a country before a large-scale military move is undertaken. So long as the average citizen has a high standard of living or sees continuing improvements in a relatively low standard of living, it is difficult to persuade him that a fundamental change in the national policy should be undertaken. However, if the situation is reversed, he is easily convinced that something should be done and that the existing national policy needs to be radically changed.

During the boom years of the late nineteen-twenties, a consistent improvement in the relatively low standard of living in Japan, Germany, and Italy satisfied their peoples that the national policies

were sound; but the catastrophic conditions that accompanied the economic debacle of the early nineteen-thirties were a powerful argument on the side of those who clamored for a change in national aims and rules. There are always potential Hitlers in every country, but in times of prosperity and peace the words of rabble rousers for the most part fall on deaf ears. Hitler himself talked and persuaded to little effect during the tranquil period of Stresemann. Just as prosperity made him unacceptable, so, conversely, did the depression give him power. Just as war with the United States would have been unthinkable to the German people in 1925–1929 after the Dawes plan had been put into effect, so would war between the United States and Japan have seemed impossible to the people of Japan in the early nineteen-twenties when they were full of gratitude for the generous expression of good will and sympathy that followed the devastating Tokyo earthquake of March 14, 1923. They may have felt hurt and bewildered by the United States' Exclusion Act of 1924, but it took the desperate social conditions wrought by the depression of 1929 and 1930 to make them lend an attentive ear to those who proposed a military solution of all their difficulties. Once embarked upon a policy of conquest, there could be no turning back short of a trial of strength between the great industrial powers of the world.

The control of raw materials has been a source of wealth and power, but this undoubted economic advantage has mattered little during periods of expanding markets. It is only during periods of economic dislocation, when economic nationalism becomes rampant and economic barriers are erected around both markets and sources of supply, that such nations as Italy, Germany, and Japan have had reason to cry out. Even then it was the tariffs designed to prevent access to markets rather than those to increase the revenues of the countries exporting raw materials that caused industrial dislocation and threw millions of people out of employment.

Once a nation is committed to military action or the risk of military action, sources of raw materials assume an entirely new significance. They become a part of the military strategy. The problems of supply formerly considered by the General Staff were largely limited to supplies for the military services. Now the supplies for industry are nearly as vital a concern as are those for the man at the front. The prosecution of modern war is to a large extent a problem of industrial production and of transportation. An adequate supply of basic raw materials must be maintained. Although

the ultimate objective of military conquest is to gain control of markets, the more immediate aim of a military campaign is likely to be control of raw materials of strategic importance to either of the belligerents.

Small-scale imperialistic wars waged by a powerful country against a weaker neighbor have from time to time in the past netted some of the people in the victorious nation a material profit. The large-scale modern wars of great industrial nations, fought to the point of exhaustion of all concerned, have thus far shown no promise of a material profit to victor or vanquished. The intangibles are difficult to evaluate; but even in the countries that have been ruthlessly and brutally exploited in the past—as have certain colonies of Germany, Holland, Belgium, France, and England—conditions have steadily improved and subject peoples, including the American Indians of the United States, have gradually achieved political and social conditions about as favorable as those enjoyed in the exploiting countries a few generations earlier.

Wars fought by the masses express man's impatience with the slow, unequal progress of social and economic liberalism. It is worthy of note, however, that the great and revolutionary changes in man's outlook and in his environment have swept across countries and continents independent of wars and national rivalry. The message of Jesus came out of a country under the heel of an invader, torn by constant rebellion. His ethical concepts have traveled through the world regardless of battles or boundaries. The budding and blossoming of science in the fifteenth and sixteenth centuries transcended ecclesiastic and national laws. International scientific collaboration has persisted to the present except for brief intervals of censorship during the periodic blackouts of civilization when Mars was the only star in a darkened sky. The Industrial Revolution, though it began in England, spread eastward until it had circumscribed the globe, and the Industrial era will continue regardless of wars. Slavery was abandoned in one great country after another without recourse to war, even in the United States, where the emancipation of slaves occurred during a great war which expressed the age-old conflict between States' Rights and federal authority.

Ethical ideals and political ideas cannot be stopped by war. Man's social, political, economic, and spiritual relationships will continue to improve, but steady, even progress is not to be expected. The distribution of raw materials will continue to affect his welfare.

When ethics rather than expediency determine national policy, when both markets and sources of raw materials are equitably administered for all, when our natural resources come to be regarded as property in which all people of the world own a joint interest, regardless of their location, it may become possible to effect a mental disarmament based on mutual confidence, friendship, and tolerance which alone can prevent future wars. In the meantime, knowledge of the economics, geology, and distribution of mineral resources is vital to intelligent planning.

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CHAPTER 5

Geology

Methods of Study and Underlying Assumptions

GEOLOGISTS like to think of their science as built on inductive and deductive reasoning; perhaps this is because, to quote from Gilbert and Sullivan's *Mikado*, "it gives an air of verisimilitude to an otherwise bald and unconvincing narrative." It can be shown that many conclusions regarding geologic processes are based on reasoning from the particular to the general or from the general to the particular; but either deductive or inductive approach, if scrutinized carefully, is nearly always found to be dependent on reasoning by analogy. If two things are identical, we may conclude that they are the same. If two things are notably similar, they also may be the same. A geologist constantly and often unconsciously uses the principle of similarity. For instance, he may know by observation the characteristics of a moraine now forming in front of a glacier. If he observes a strikingly similar deposit remote from glaciers, he may then deduce that a glacier was formerly present. However, we should not lose sight of the fact that the basis for his deductive reasoning is the similarity of the essential and definitive characteristics of the two deposits. Such a method places a premium on observation and intuition or, as the geologist prefers to call it, horse sense. A geologist blessed with these attributes in large measure succeeds in making verifiable predictions and is thus entitled to recognition as a scientist.

In addition to reasoning by analogy, a geologist is constantly required to make use of extrapolation and interpolation, two somewhat inexact processes which, when carried to extremes, may lead to completely erroneous conclusions. If a geologist sees a bed of rock slanting downward into the earth, he would feel justified in extrapolating it to some depth and would probably hazard a forecast that it would appear at a certain depth in a well, if he were allowed to choose the location of the hole. A high degree of suc-

cess has attended such predictions. In some places geologists have found that land is rising slowly out of the sea, perhaps a few feet in a century. With his bent toward extrapolation, the geologist projects the rate of uplift into the future and deduces what effect such movements will have on the earth's crust here many thousands of years in the future. In other words, he uses the vast stretches of geologic time to integrate the infinitesimals of the yearly change. Such conclusions cannot be proved, but we may seek for analogues among structures formed in the past. It is apparent from the nature of the subject with which the geologist deals that many of his conclusions must be incapable of rigorous proof or even of being tested by predictions. Their acceptance must rest on their "reasonableness" and their ability to explain all the factors known to bear on the problem.

Two fundamental and almost universally accepted assumptions underlying geologic thought are: 1) processes operating today have operated in the past; 2) precise observations over many years on geologic processes such as erosion, transportation of debris by wind and water, elevation and depression of the land, volcanic activity, and the behavior of organisms, yield a more and more dependable knowledge of geologic processes that have operated during geologic eras. A third assumption (based on analogy) is that experimental work may be used as a guide to understanding geologic processes. Synthesis of rocks and minerals in the laboratory suggests methods by which they may have formed in nature. However, laboratory work alone means little until it is correlated with investigation in the field.

Geologic Time

An appreciation of geologic time is quite as difficult to grasp as is an appreciation of astronomic distances. It is almost universally true that a feeling for the reality of a time lapse does not extend far back of the individual's birthdate. A comprehension of the time interval represented by the two decades from 1920 to 1940 is quite real. For most of us it is rather different from the sense of time we feel for the interval between 1820 and 1840 and far different from the idea we have of the period 3040 to 3020 B.C. Several lines of evidence combine to indicate that the world was born between two billion and three billion years ago and that it has had approximately its present size for the last two thousand million years. It is easy to see that the cumulative results of apparently

insignificant geologic changes going on about us today might be truly startling if continued through an appreciable part of this incomprehensibly vast stretch of time.

Using the present-day rates of deposition of sediments, geologists long ago tried to compute the time necessary for the accumulation of the sedimentary rocks of the earth's crust. Similar estimates have been made of the length of time that is required for agents of erosion to remove the land. These calculations indicate that geologic time should be measured in the hundreds of millions of years. However, it was not until the discovery of radioactivity that a really quantitative method for determining the age of rocks was at hand. Prior to this time, physicists had insisted that the earth could not be more than a few tens of millions of years old at most, and though their mathematics was unimpeachable, their assumption that the age of the earth could be calculated from the length of time it should take to cool involved many simplifying assumptions which vitiated the result. In 1905, B. B. Boltwood suggested the possibility of checking the supposed age of strata by applying the laws of radioactive disintegration to radioactive minerals.(1) The rate at which uranium breaks down into a series of unstable disintegration products that finally end up as lead has been accurately established. An analysis of a uranium mineral for the amount of lead that has formed and the amount of uranium still left indicates the length of time that the mineral has been decomposing. If the geologic relations are such that it can be shown that the mineral formed at the same time as did the enclosing rock, this lead-uranium ratio can be used to compute its age.

The oldest radioactive minerals found have a lead-uranium ratio that corresponds to an age of approximately 2,000,000,000 years. This vast stretch of geologic time has been subdivided by geologists in much the same way that history has been subdivided by historians. Just as an historian rather loosely subdivides time into such eras as prehistory, ancient history, mediaeval history, and modern history, so does the geologist divide geologic time into four long eras. The first great stretch lasted until about 500,000,000 years ago and is called the pre-Cambrian. The ancient geologic era that stretches from 500,000,000 years ago to approximately 250,000,000 years ago is the Paleozoic era; the next era lasted until 70,000,000 years ago and is known as the Mesozoic era. The remainder of geologic time is included in the Cenozoic era. Each of these geologic eras has been subdivided into various geologic periods, and the

periods in turn are locally subdivided into smaller intervals of geologic time. Local place names are tied to the formations that were deposited during these smaller intervals, but the major subdivisions of geologic time everywhere have the names given in the accompanying table.

TABLE IV

SUBDIVISIONS OF GEOLOGIC TIME

Era	*Period*
Cenozoic	Quaternary Tertiary
Mesozoic	Cretaceous Jurassic Triassic
Paleozoic	Carboniferous * Devonian Silurian Ordovician Cambrian
Pre-Cambrian	Late pre-Cambrian Middle pre-Cambrian Early pre-Cambrian

* In North America the Lower, Middle, and Upper Carboniferous are ranked as periods and called the Mississippian, Pennsylvanian, and Permian periods, respectively.

An appreciation of the incredibly long period in which the rocks at the earth's surface have been forming may be gained in part from the study of the gradual evolution of life shown by differences in fossils found in ancient and in young rocks. Examination of the fossils found in strata indicates a gradual change in the character of the fauna during geologic time. In the Cambrian period, the highest form of life that existed was a shellfish. In the Ordovician, the first real fish appeared. The earliest amphibian of which we have record is preserved in Devonian rocks, and reptiles did not develop until the Carboniferous period. The first small mammals, who were pitifully weak and handicapped in the struggle for existence as compared with reptiles then extant, came into being in the early part of the Mesozoic era. In general, fossil faunas above and below a given stratum will be different; and the gradual changes in

fauna and flora allow a paleontologist to correlate with confidence widely separated remnants of a given fossiliferous stratum.

The age of relatively few rocks can be determined by the method of lead-uranium analysis. Commonly the age of a rock is approximated by other means. If the age of a stratum containing a characteristic group of fossils has been established, strata having these same fossils, even though they may be far distant, are thought to be about the same age.

Perspective

Geologic concepts are most easily acquired if we strive always for a sense of proportion. When we consider the great ocean deeps and the mighty Himalaya Mountains we normally consider them as would an animal some five or six feet tall, thus using our height as the frame of reference. However, it is much more appropriate to consider the topographic and structural features of the earth in relation to the earth itself. A recitation of figures for the size of the earth does little to aid our comprehension of relative scale. Let us therefore peel the earth down to a size that we can readily visualize. If we reduce it to one five-millionth of its bulk, we would have a globe approximately eight and one-quarter feet in diameter, and one inch would measure eighty miles. On this scaled-down model, the greatest ocean deep, which drops approximately seven miles below the surface of the ocean, would show as a groove cut slightly less than one-tenth of an inch. Mount Everest would tower one-sixteenth of an inch above sea level. The deepest bore hole in the world would penetrate approximately one twenty-fifth of an inch into the globe and the deepest mine about one-fortieth of an inch. In only a few places in the world has sedimentary rock accumulated to a thickness of more than 30,000 feet, but in a few troughs the thickness reaches the amazing figure of 50,000 feet. On the eight-foot globe, this would be represented by a veneer an eighth of an inch thick. In most places, however, the thickness would be much less. If we could cut right through this sphere, we should probably find that in continental areas granitelike rocks would extend from one-quarter of an inch to an inch below the surface and there give way to dark-colored igneous rocks rich in iron and magnesium, similar to the trap rock lavas so abundant in the northwestern part of the United States. Material of this type would extend to approximately 23.75 inches below the surface, where it would change rather abruptly to a metallic core which probably consists

of nickeliferous iron, if we can use the composition of meteorites as a guide. The metallic core is probably molten, but the outer shells are essentially solid rock except for local pockets of molten material less than a half inch below the surface. Our assumptions concerning the interior of the earth are based largely on a comparison of the rate earthquake waves travel through different known rocks with the rate they travel along different paths through the globe.

If in this model of the earth we were able to speed up time as much as we have diminished the relative size, six seconds would represent approximately one year. On this time scale our model is approximately 500 years old. The Paleozoic rocks commenced forming approximately 100 years ago, the Appalachian Mountains which formed at the end of this era are 50 years old, and the earliest Cenozoic rocks are only 14 years old! As 100,000 years would be represented by approximately a week on this time scale, we can say that the mote called man has existed only a few weeks.

Geologic Processes and Formations

Erosion

Rocks at the surface of the earth are softened by exposure to the weather. Chemical agents such as water, oxygen, carbon dioxide, and active organic compounds formed by processes of decay, combine with heat and frost to break down the original minerals of a rock and change them into soil. In many places it is possible to see the complete gradation from soil through partially weathered rock into fresh bedrock that has as yet been untouched by the weather. In many road cuts in the southern Appalachians there are excellent exposures of hard granite at the level of the road, fertile soil at the surface fifty feet above, and between the two a complete gradation from the granite to the soil.

The movement of soil has been witnessed by all of us. During periods of drought, tremendous quantities may be moved by the wind in the dust bowl area. In these same regions disastrous soil erosion may take place during years that have unusual precipitation. Valuable farm lands are destroyed not only through the action of wind but also through transportation of the top soil by stream action and gulleying. The amount of soil that is annually carried by our large slow-moving rivers is enormous. The Mississippi River discharges on an average about a million tons of water

per minute. This water carries about two hundred tons of dissolved lime and salt which has been extracted from the rocks and soil of its drainage basin. It also carries into the Gulf each minute about eight hundred tons of solid matter in suspension. To transport its daily load of silt and mineral matter would require nine hundred trains a day of fifty cars, if each car held twenty-five tons.

In addition to loose incoherent soil that is easily swept into the nearest stream by any little trickle of water that passes over it, hard fresh rocks are broken down and abraided by the solid particles swept across them in the stream. The tremendous destructive power of a river in flood is demonstrated all too frequently. But even if one has stood on the banks of a glacial torrent and felt the ground shake to the thud of boulders moved by the rushing water, it is difficult to realize the mechanical work that is being carried on by this fluid saw.

The speed with which erosive agents work varies with the resistance of the rock. Resistant granite bordered by clay would be etched out by erosive agents until it stood up as a hill above the clay lowlands. The striking relationship between land forms and the comparative resistance of the bedrock to erosion is nowhere in the world shown better than in the region of the Grand Canyon of the Colorado River in Arizona. This canyon has been carved a mile deep by the river, and all its fantastic rock forms simply reflect the unequal hardness of strata beaten by rain, wind, and river. (See Figure 6.)

The sea is constantly attacking the land, and the fury of its charge during a storm may entirely change a local coastline. Standing on a cobblestone beach at such a time, one is impressed by the fact that the roar of the waves is not so loud as is the noise made by the cobblestones tumbling over one another as they are rushed forward by the advancing waves and then dragged seaward by its retreating backwash. This noise, which sounds like an express train passing over a high trestle, is an audible manifestation of the rapid abrasion that is being carried on. Actual tests show that an ordinary brick will be completely reduced to powder by the usual wave action on an ocean beach in less than two weeks.

Sediments

The detritus carried by stream action, wind, and ocean currents must ultimately come to rest somewhere. The higher lands are constantly being whittled down by erosion and transported to ocean

Spence Air Photos.

Fig. 6. Grand Canyon of the Colorado, looking east from a point near Hermit Creek. The river runs in a steep-sided gorge cut in hard, early pre-Cambrian igneous and metamorphic rocks above which lie nearly horizontal pre-Cambrian and Paleozoic sediments. The profile of the canyon above the inner gorge reflects the relative resistance of the interbedded limestone, shale, sandstone, and quartzite that comprise the section above the granite and gneiss.

or lake basins. Were it not for movements of the earth's crust, all continents would long since have been reduced to sea level and the ocean would have won its never-ending war with the land.

The material moved by the agents of erosion ranges in size from immense glacial boulders to extremely fine-grained mud and clay. When the heterogeneous material reaches the end of its journey, it is assembled as a sediment and is ready to start the long, slow process of hardening into solid rock strata. The sediments are thus hand-me-down products; they are made-over rock. As Hutton once said, "Much of the earth's surface is built out of the remains of the past ages." The bulk of the sediments is only a very small part of that of the earth, but, spread as a thin veneer, they cover nearly three-quarters of the earth's surface. If we consider that the crust of the earth is approximately ten miles thick, 95 per cent of it is igneous rock and only 5 per cent sediment. Of the sediment, 32 per cent is derived from sand, 18 per cent from marl or limestone,

and 50 per cent from clay. Sediments include both the hardest and the softest rocks. Lignite and clay are especially soft and quartzite is extremely hard. There are all gradations from mud and clay through shale to argillite and slate; from marl or limey shell accumulations to limestone or dolomite; from sand through sandstone to quartzite; and from gravel to conglomerate or "pudding rock." The hardness of any sediment depends on its history as well as its composition. Heat, water, chemical reaction, pressure of overlying rocks, and age all play parts in these changes.

Although the material making up sediments may be deposited as lakebeds or riverbeds or may be dropped from the wind as an aeolian deposit, by far the most widespread and abundant sediments are those that have accumulated under the sea. Marine beds are commonly laid down in a definite sequence due to the sorting effect of moving water. Coarse gravel is dropped close to shore, while sand is carried farther out. Clay travels farther than sand, and in the clear water just beyond the zone where clay and silt drop to the bottom, limestone may be expected. When shorelines rise or sink, as they frequently do, these beds overlap one another like shingles in a roof. Gravel may be laid down upon sand when a coast rises, but when the coast sinks, the zone of sand deposition ad-

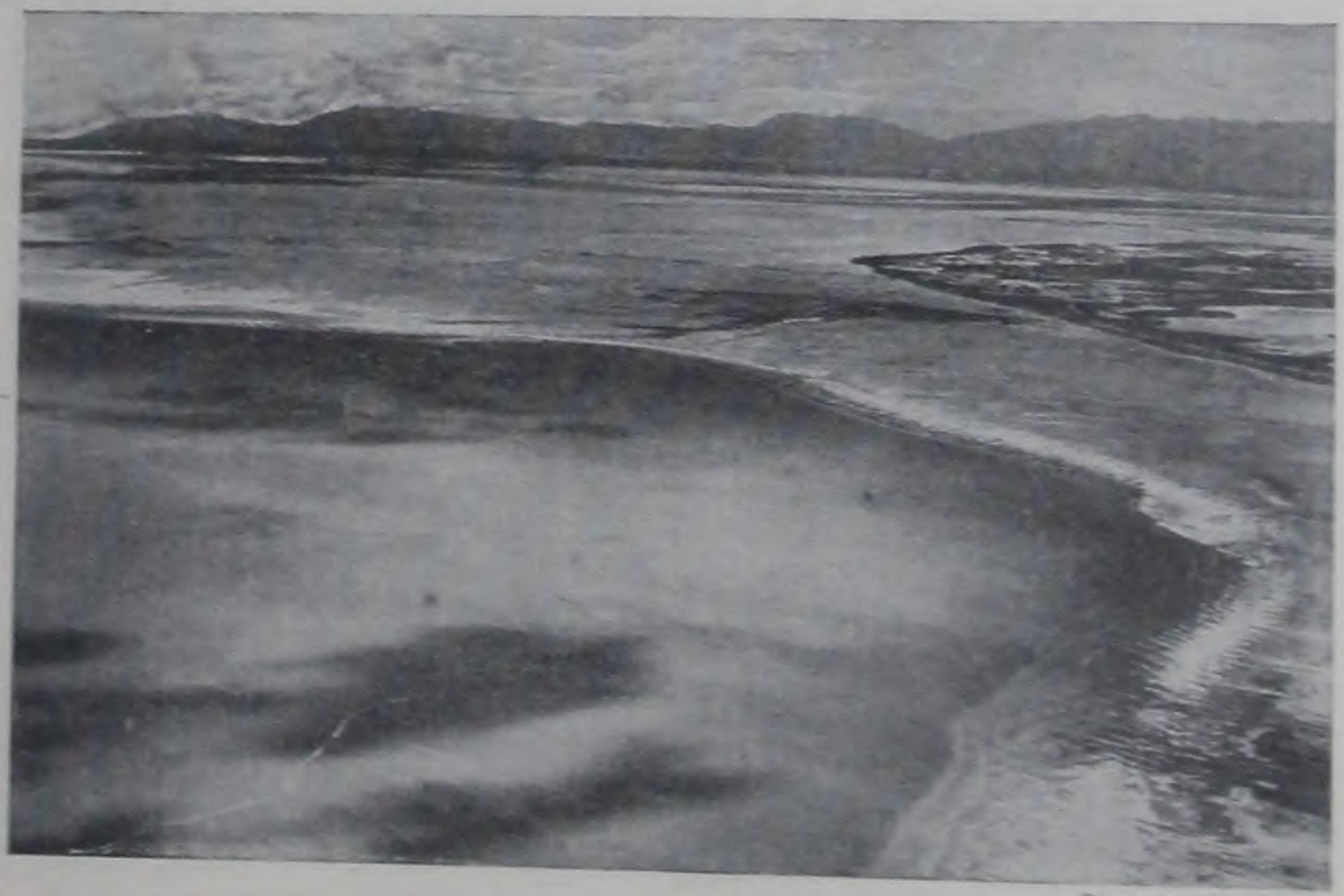

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Fig. 7. Great Salt Lake, Utah, an evaporating remnant of an ancient fresh-water lake. The white residue of salt left by the receding water has already hardened into a solid salt bed and covers hundreds of square miles.

vances shoreward and sand is deposited upon the gravel. The areas of deposition of the other sediments will be shifted in a similar way. (See Figure 9.)

If streams or springs fail to supply fresh water to a lake as rapidly as the water is evaporated from its surface, the proportion of dissolved solids steadily increases. Eventually, such a body of water would become saturated with certain chemical compounds and further evaporation must precipitate salts of various kinds. (See Figure 7.)

If an arm of an ocean is cut off by sand bars and if fresh water does not enter this stranded bay, evaporation will cause successive precipitation of marl, gypsum, salt, magnesium chloride, and a thin layer of potash. These chemical precipitates are known as evaporites. Nearly all deposits of gypsum, salt, and potash are formed by evaporation of sea water. A small amount of marl or limestone is also an evaporite but most limestone is the result of an accumulation of shells and similar hard parts of marine organisms.

Since younger sediments are always deposited on top of older rocks, it is customary to assume that the age of a rock increases as we go deeper into the geologic strata. This is not everywhere true, however, as locally we find older rocks that have been pushed up

Spence Air Photos.

Fig. 8. An unconformity in the making, Butte Valley, Panamint Range, California. Folded beds of Carboniferous age are exposed in a butte that is being buried in sediment washed down from the surrounding hills.

and that now lie on top of the younger ones (see Figure 13); but even here the assumption that originally the age of the beds accorded with their superposition would be correct.

Ancient sedimentary beds may be raised up, tilted, partly worn down, and then resubmerged and covered by new layers of sediment

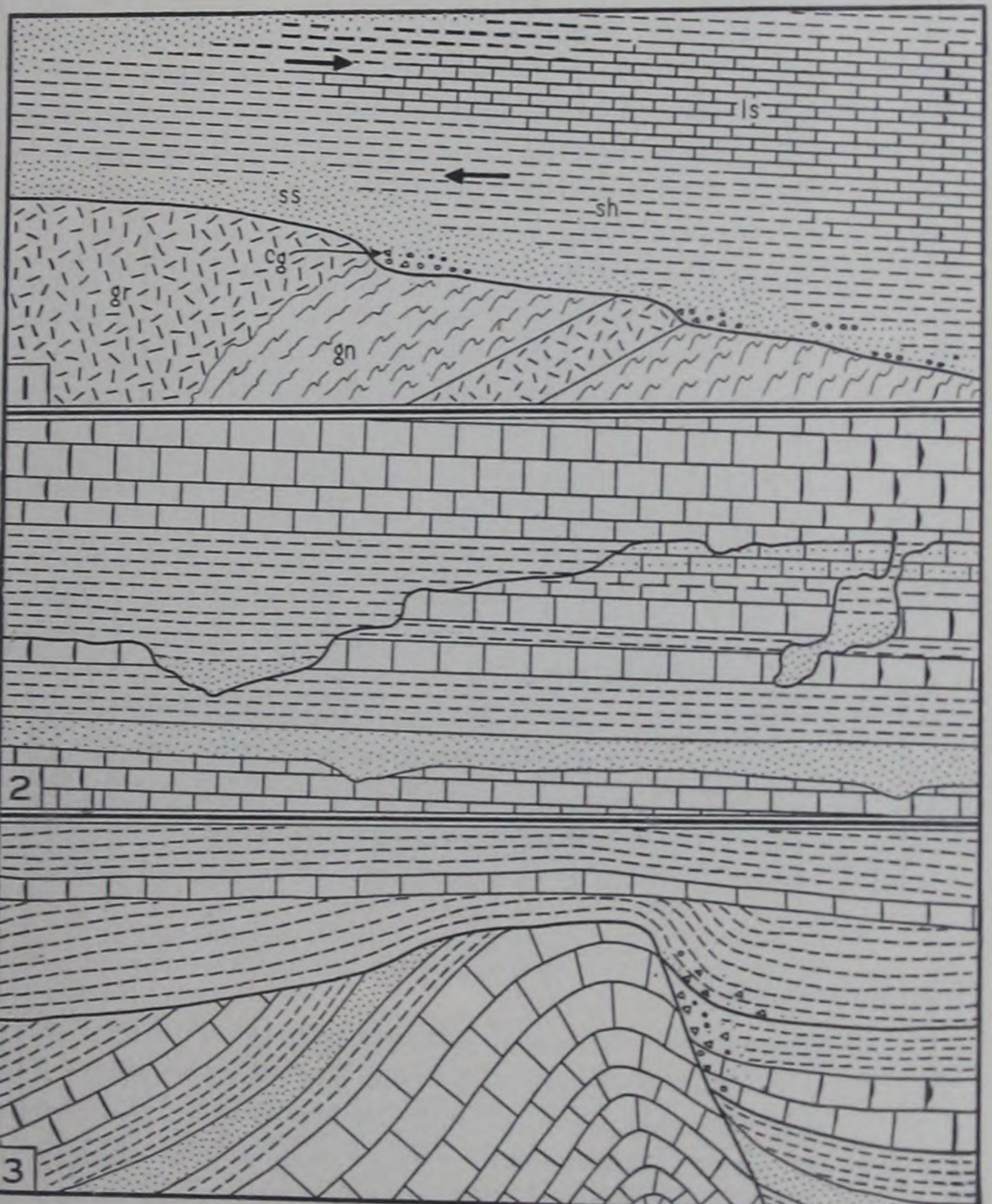


Fig. 9. Different types of unconformity and overlap:

(1) Sediments deposited by a sea that first transgressed to the left and then receded to the right. gn, gneiss; gr, granite; cg, conglomerate; ss, sandstone; sh, shale; ls, limestone.

(2) Unconformities in parallel strata; the upper one is called an erosional unconformity, the lower one is called a disconformity.

(3) An angular unconformity.

whose bedding naturally does not conform to the underlying tilted rock. (See Figure 8.) The unconformity of two sets of strata indicates a gap in the geologic record. A less obvious type of unconformity exists when ancient sedimentary rocks have been raised above sea level without tilting and, after an interval of time, resubmerged. (See Figure 9.)

Many valuable mineral deposits have been formed by processes of sedimentation. Chemical sediments or evaporites are the chief source of salt, potash, borates, nitrates, and gypsum. The broad salt-covered flats bordering the slowly desiccating Great Salt Lake show one way in which salt beds of the past have formed. Minerals resistant to weathering are concentrated in mechanical sediments such as river and beach sands; here are found valuable deposits of gold, platinum, tungsten, tin, and diamond. These valuable sedimentary concentrations are called placers. Iron and manganese occur both as mechanical sediments and as chemical precipitates. Mineral deposits of these types exhibit the characteristics of sediments. Although they are blanketlike in form and may extend over wide areas, they are confined to certain definite strata. Just as the gradation from sand into clay may take place abruptly within a few feet or gradually through a much greater distance, so may the sedimentary ore deposits change abruptly or gradually into sediments made up of valueless minerals. If the type of sediment that contains the mineral deposits can be recognized, it is possible to make a shrewd guess as to the general shape of the deposit. Thus, if gold is found in sand that was deposited along a beach, a map of the ore-carrying zones would have quite a different appearance than if the sand were deposited as part of a river channel.

Crustal movements

To the geologist, the "eternal" hills are evanescent things—here today, gone in a few thousand millennia, leveled by erosion. The geologist, however, also sees incipient mountains and plains where now only the ocean meets the eye. We are accustomed to thinking of the earth's crust as relatively stable, except in zones where earthquakes suddenly and visibly dislocate it. However, there is evidence that less spectacular but very definite motion is taking place slowly in many parts of the world. A careful record of lake levels shows that in the Great Lakes region the land is rising at a rate of approximately sixteen inches a century; and tidal gauges

show that in the Baltic Sea certain localities are rising at a rate of more than three feet per century. Such rates seem infinitesimal when reduced to the daily or even the yearly rate of movement; but, if such rates were to continue for only a few hundred thousand years, the land would be several thousand feet above its present level. In only twenty thousand years the Baltic Sea would be almost completely drained except for mere residual lagoons, none of which would be more than forty miles in length. On many coasts, wave-cut beaches have been elevated well above the ocean and stand out as prominent sloping benches between beaches now being formed. (See Figure 10.) Extensive beds of marine rocks

Spence Air Photos.

Fig. 10. A rising coastline, Laguna Beach, California. Beaches cut by recent wave action show in the scalloped bights between low headlands which preserve earlier beaches now raised well above wave action.

are found more than a thousand miles from the nearest ocean, and the former presence of ancient seas is clearly established by the character of the fossils that the rocks contain. When the strata are carefully correlated and mapped, it is possible to reconstruct the extent of the ocean at different periods in the earth's history. We thus find that at various times our North American continent has been an odd collection of islands and inland seas. Some of these islands have persistently kept their heads above water for long stretches of time and are called positive, or "high," areas. Other areas that are per-

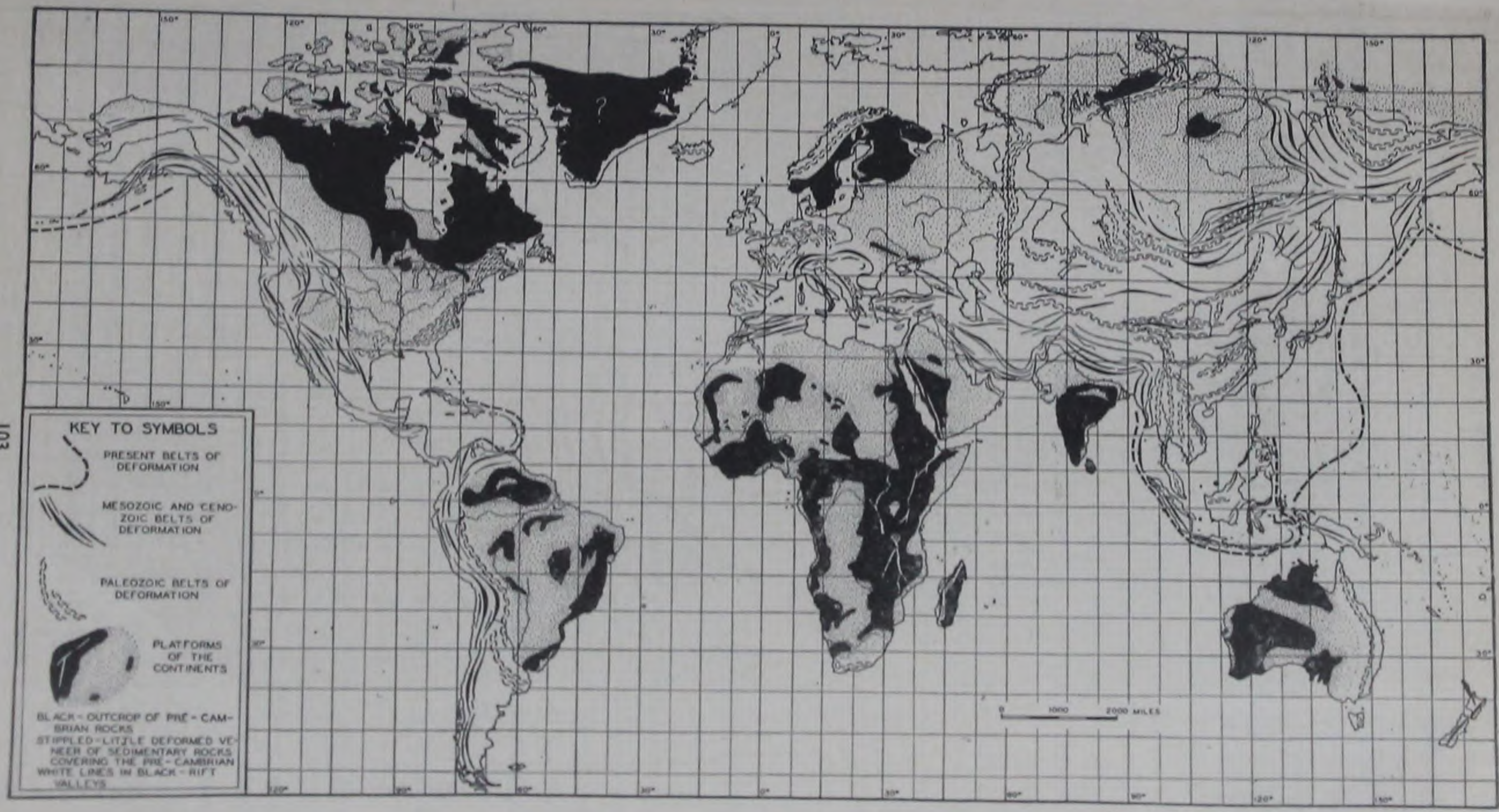
sistently low and sites of sedimentation are known as negative, or "low," areas.

Many mountains have raised themselves from low sea-covered troughs or at the edges of negative areas. Apparently the earth's crust sagged into a trough while a steadily increasing load of sediment accumulated there. Later, after the weak sediment had been warped down deeply, compressive forces in the earth's crust made it buckle and break along the sea trough as though the crust had been notched. Although such crustal failures are usually accompanied by volcanic fireworks, many mountains bulge up without them.

The broad, slow uplifts in the Great Lakes region in North America do not involve folding of rock strata. These regional uplifts are known as epeirogenetic movements.

Throughout geologic history there have been periodic intervals of local or world-wide crustal convulsions during which belts of the earth's crust have been folded and mountains formed. This process of mountain-making is known as orogeny. Although geologic periods were originally separated on the basis of the sharp change of fauna in strata deposited during successive periods, it has been found that breaks in the geologic record between periods commonly correspond to local or world-girdling orogenic movements. The most important times of widespread orogeny occurred: 1) in pre-Cambrian time, 2) at the close of the Paleozoic era, and 3) in the early part of the Cenozoic era. These great disturbances are known as revolutions and have been named; the one that closed the Paleozoic era is commonly known as the Hercynian revolution, and the one that closed the Mesozoic era is known as the Laramide revolution. Most orogenic movements are confined to long, narrow belts. Those of Laramide and later age correspond with our present major mountain systems and with chains of active volcanoes. Only the stumps of earlier mountain systems remain, except where they have been rejuvenated by a much later movement. The distribution of Hercynian and Laramide folds is shown in Figure 11.

Nearly all of the active volcanoes in the world are included in two narrow belts, where also occur most of our active earthquake zones. One belt borders the Pacific Ocean forming the so-called "Circle of Fire." The other crosses from the western Pacific through the southern part of Asia and Europe to the Atlantic Ocean. A branch of the belt diverges south through east-central Africa, along the great Rift Valley. These narrow zones apparently


KEY TO SYMBOLS
PRESENT BELTS OF DEFORMATION
MESOZOIC AND CENOZOIC BELTS OF DEFORMATION
PALEOZOIC BELTS OF DEFORMATION
PLATFORMS OF THE CONTINENTS
BLACK - OUTCROP OF PRE-CAMBRIAN ROCKS
STIPPLED - LITTLE DEFORMED VENEER OF SEDIMENTARY ROCKS COVERING THE PRE-CAMBRIAN
WHITE LINES IN BLACK - RIFT VALLEYS
0 1000 2000 MILES

Compiled by A. J. Eardley and T. S. Lovering.

Fig. 11. Structural elements of the continents; mountain systems of the world, ancient and modern.

mark flaws in the earth's crust where active movement is to be expected.

Properly speaking, earthquakes are elastic waves that accompany the breaking apart of portions of the earth's crust. The zone of fracturing is known as a fault, and the process of breaking is known as faulting. The direction that the walls of a fault move may be horizontal or vertical or at any angle between. Thus, in the Wrangel Island earthquake of 1899, the coast rose suddenly forty-seven feet above the sea. In most of the California earthquakes, on the other hand, the movement is almost horizontal. At Skinner's Ranch, near Olema, California, in the earthquake of 1906, the front sidewalk was moved horizontally eighteen feet to the back of the house! In other types of earthquake one side moves upward at an angle, causing both a vertical and horizontal offset of normally continuous features. Many faults are exposed in folded and fractured rocks that mark sites of earlier orogenic movement. It is inferred that slow folding is probably taking place in various places in the earthquake zones of the world today even though quantitative measurements of the folding have not yet been satisfactorily made.

Igneous activity

The behavior of earthquake waves that pass through the earth indicates that the earth consists essentially of solid rock for many hundreds of miles below the surface. However, many shallow pockets of molten rock or magma, as it is known, probably lie twenty miles or so from the surface. Volcanoes commonly lie along great fracture zones, and the eruption of one is often the signal for the awakening of its neighbors. The factors that cause generation of magmas are not well understood but are generally believed to be related to movement of large blocks of the earth's crust.

After a magma has been formed many miles below the surface, it may cool slowly and crystalline *in situ* or it may be forced upward toward the surface. In the past, great quantities of igneous rock have moved up to within a relatively short distance of the surface without actually breaking through to form volcanoes or fissure eruptions. The igneous masses that did not reach the surface are known as intrusive rocks, and those that have been poured out from volcanoes or open fissures in the earth's crust are known as extrusive rocks or lavas. The names given to intrusive bodies of different shapes and structural relations are indicated in Figure 12.

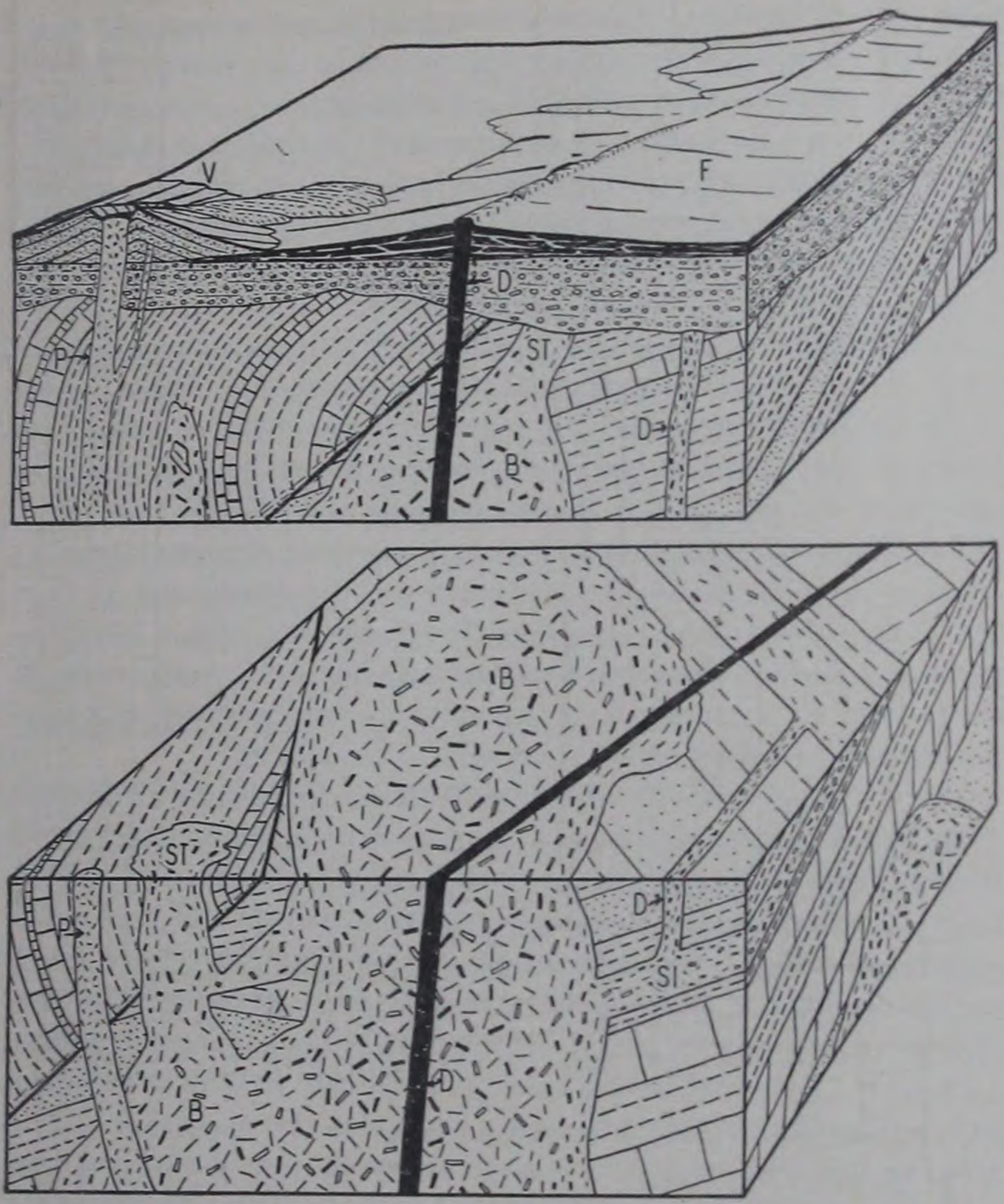


Fig. 12. Types of igneous rock. B. batholith; D, dike; F, fissure flow; P, plug; Sl, sill; St, stock; V, volcanic cone; X, xenolith.

The grain or texture of an igneous rock depends chiefly on the speed with which it cools, its viscosity, and the amount of movement suffered while crystallizing. Just as a pan of fudge will be coarse-grained and sugary if unstirred, cooled slowly, and too thin or watery, an igneous rock that cools slowly without movement and crystallizes from a magma of low viscosity will have large crystals. Such conditions are most common near the end of the period of crystallization in a body of magma far below the surface. Conversely, a thin layer of viscous lava that cools rapidly may be a

glass or, if crystalline, extremely fine-grained. Igneous rocks with very coarse crystals are called pegmatites, a moderately coarse-grained texture is called granitoid, and fine-grained rocks are called felsites or traps, depending on whether they are light or dark colored. If coarse crystals are mixed through a finer-grained ground mass the texture is said to be porphyritic, and the rock is a porphyry.

Intrusive rocks are classified according to their composition and texture. A large part of all intrusive rock is made up of granite, a light-colored, coarse-grained rock; but only a comparatively small amount of lava (rhyolite) has this composition. Great masses of dark-colored extrusive rock known as trap rock or basalt are found in many parts of the world, but the coarse-grained intrusive equivalent of trap, gabbro, is not especially abundant. In general, dark-colored rocks are rich in iron and magnesia and are known as mafic or ultra-mafic rocks, depending on the proportion of iron and magnesia present. Light-colored rocks are richer in silica, alumina, potash, and soda and are termed silicic. If potash and soda are present in unusually large amounts and the rock has less than the normal amount of silica, it is said to be alkalic.

There is good evidence for the conclusion that nearly all igneous rocks began as basaltic magma. Just as salts of different compositions separate out successively when hot, saturated brine is cooled, so do different minerals separate out in a definite order as a hot magma is cooled. The first minerals that crystallize have much iron and magnesia but contain relatively little silica and alumina. The last minerals to separate out are rich in silica, alumina, potash, and soda. If crystallization takes place slowly in a large chamber, iron-rich crystals may settle to the bottom of the magma and there form an iron-rich igneous sediment known as a magmatic segregation. As the mafic minerals crystallize and settle, the magma is robbed of much of its iron and magnesia and thus the silica, alumina, potash, and soda that remain form a constantly increasing proportion of the cooling magma. Such a progressive change in composition is known as magmatic differentiation. By this process a basaltic magma may change until it has the composition of granite.

Metamorphism

When physical or chemical conditions change after a rock has formed, they may cause an easily recognized response in the texture or composition of the rock. Any change in character may be prop-

erly denoted as metamorphic, but commonly the term "metamorphic rock" is reserved for those rocks that have suffered great changes under severe conditions of heat and pressure. The gradual hardening or induration of a marl transforms a loose, incoherent, limy deposit into a solid limestone; this transformation is the normal result of burial and the heavy uniform pressure of a thick overburden. If the limestone is severely deformed, however, it may change into a marble, a typical metamorphic rock. This change is accelerated by heat and the presence of water or watery igneous emanations. A clay changes successively into shale, argillite, slate, and schist. This last step, in which a fine-grained cleavable rock is transformed into a foliated, well-crystallized schist, probably requires shearing in the presence of hot, watery fluids. Under the same conditions, a massive, igneous rock breaks down into a coarsely foliated metamorphic rock called gneiss. Continued metamorphism causes igneous and sedimentary rocks to become so similar that it may be almost impossible to tell the character of the original unmetamorphosed rock.

Ore deposits related to igneous rocks

The igneous nature of most magmatic segregations is apparent. (See Figure 13.) Some of these igneous sediments constitute valuable ore bodies; they are important sources of diamonds, chromium, nickel, platinum, and copper. Many other deposits show a less obvious igneous origin, but the genetic relation of a large number of ores to molten, intrusive rocks seems clearly established by field evidence.

The chemistry of ore deposition is not thoroughly understood, but the general process by which ores are concentrated seems fairly clear. Various gases dissolve in liquid magma in the same way that air dissolves in water. Water vapor is by far the most abundant of these gases, but a study of volcanic exhalations shows that fluorine, chlorine, sulphur, carbon dioxide, and other gases are present in minor amounts. The amount of gas that can be retained by a magma increases with pressure. Thus, an igneous rock that formed beneath a thick cover may have originally carried a considerable amount of water vapor and very active acid-forming gaseous elements. As the magma solidified into rock, these highly mobile compounds would be constrained in a smaller and smaller volume of liquid until eventually they could no longer be held in solution and then would free themselves from the magma as very fluid,

watery, igneous emanations. These fugitive fluids would be saturated with the more soluble constituents of the magma, such as iron, zinc, lead, copper, silver, gold, and certain other elements. Some magmas were apparently rich in ore compounds and others were relatively barren.

A large proportion of the ore deposits of the world are related to intrusive igneous rocks. The steadily accumulating evidence shows that most of them are a by-product of the intrusive activity of upwelling molten rocks that halted hundreds or thousands of feet below the surface. Just as incrustations of sulphur and other minerals form in volcanic vents at the surface today, so have many minerals formed far below the surface in cracks and fissures. Although some

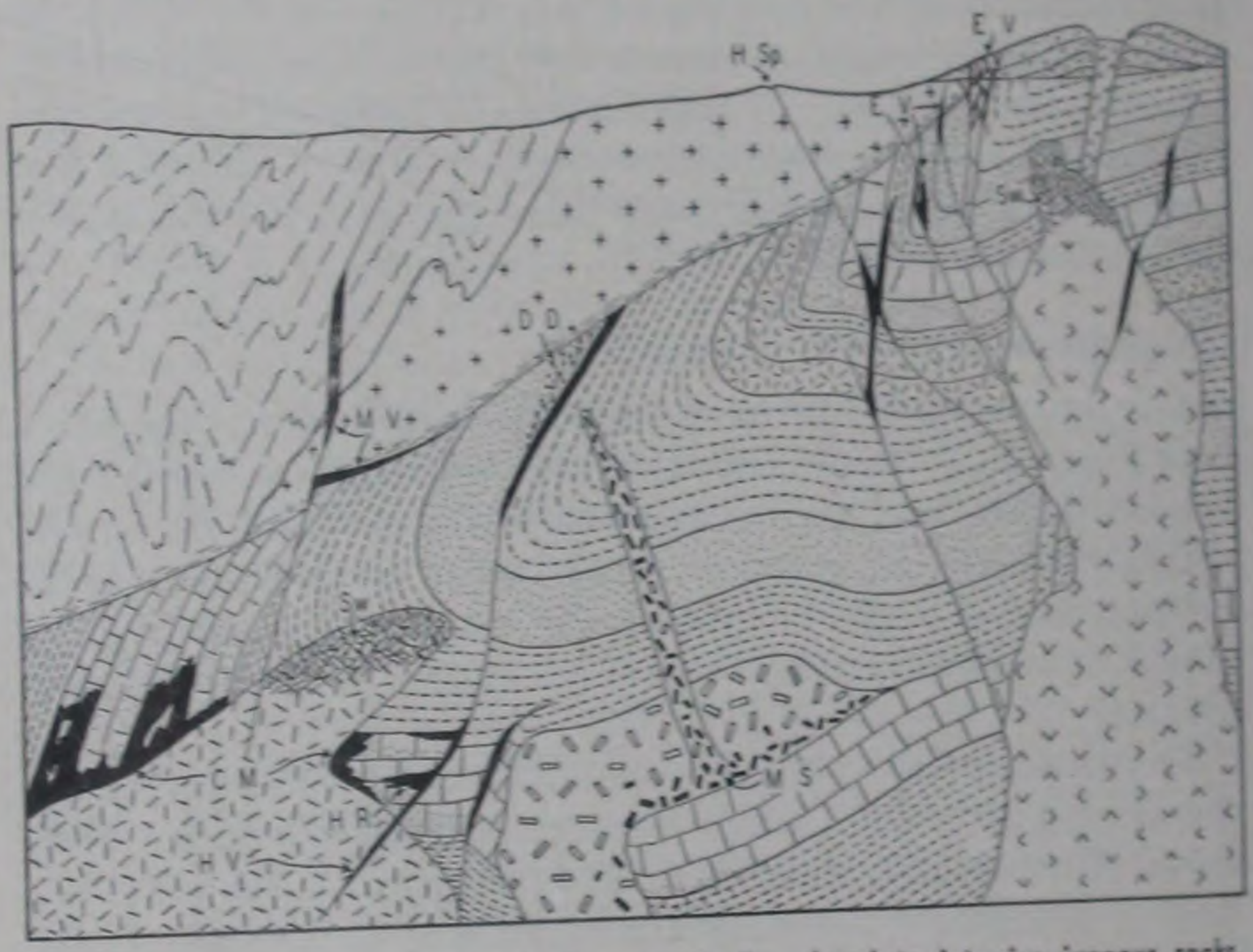


Fig. 13. Common types of ore bodies genetically related to intrusive igneous rocks. C M, contact metamorphic deposit; D D, disseminated deposit; E V, epithermal vein; H R, hypothermal replacement deposit; H Sp, hot spring deposit; H V, hypothermal vein; M S, magmatic segregation; M V, mesothermal vein; S w, stockworks.

ore deposits may have formed from gases, a far larger number of them probably formed from watery solutions that were maintained as a condensed system by either pressure or cooling. The common genetic types of ore deposit are shown diagrammatically in Figure 13.

Many minerals that were able to withstand the high temperatures existing when they formed are unable to resist the destructive action

of air and rain when they are finally uncovered by erosion. The unstable minerals of the original or primary ore are either dissolved or decomposed into soluble and insoluble portions. Dissolved material may be carried away by streams or sink back into the earth in the water that percolates downward to the water table. Here, where the solution is out of reach of air, some of the soluble material may crystallize out of solution and form new ores. Such ores are often richer than the original material that was leached by the descending ground water. The insoluble portions that accumulate at the surface are known as residual ore deposits, and the reprecipitated ore minerals that occur at the water table are known as ores formed by secondary enrichment or, briefly, as secondary ores. Different types of enrichment due to weathering are shown in Figure 14. A knowledge of the chemistry involved in surface reac-

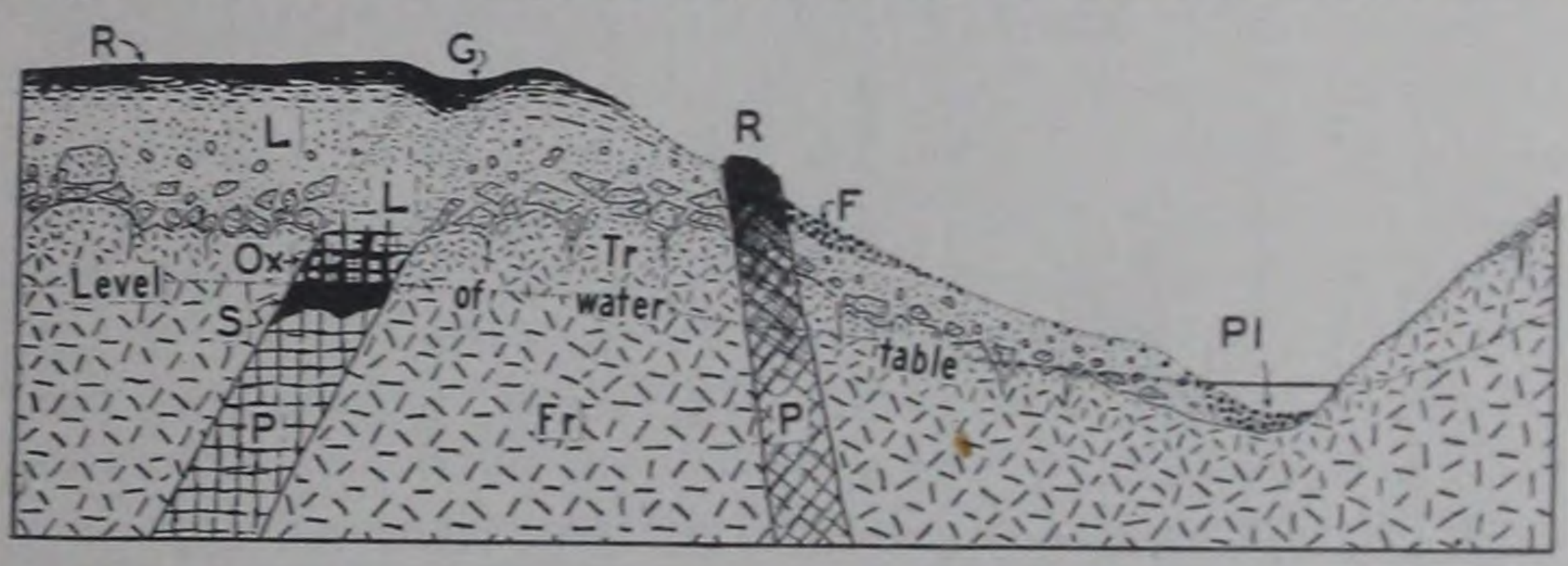


Fig. 14. Types of enrichment due to weathering. F, float; Fr, fresh rock; G, gossan; L, leached zone; Ox, oxidized zone; P, primary ore; Pl, placer; R, residual deposit; S, secondary suphide ore; Tr, transition zone.

tions has enabled geologists many times to guess that an enriched zone lay below the surface of what appeared to be a barren outcrop.

Minerogenetic Epochs and Provinces

About 1900, the great French geologist, De Launay, pointed out that during some periods of the earth's history certain unusual conditions that produced valuable mineral deposits have existed over large parts of the world.(4) The coal beds of England, India, and some of those of the eastern United States were laid down at the same time during an early period marked by a world-wide mild climate. The abundance of coal in beds of this age gave a name to the period, the Carboniferous. Again, during times of long-continued aridity, extensive salt and gypsum deposits formed in many places. A geologic revolution, during which mountain-

building occurs in narrow zones that encircle the earth, may witness widespread intrusion within these orogenic belts. The intrusions may in turn be accompanied by certain characteristic types of ore. Waldemar Lindgren, the world-famous American mining geologist, suggested the term minerogenetic epochs for the time when conditions favored geologically rapid formation of similar valuable deposits simultaneously in many parts of the earth's crust, and suggested the use of the term minerogenetic provinces for the restricted areas in which such deposits occur.(6)

As already noted, some mineral deposits are essentially sediment. Where climatic conditions are suitable and source materials available, it is to be expected that beds of a sedimentary ore may form over wide areas at approximately the same time.

It has long been recognized that certain kinds of ore deposit are characteristically associated with some varieties of igneous rocks. Deep-seated igneous rocks are abundant in pre-Cambrian areas, and some distinctive types are commonly associated with gold, platinum, iron, chromium, nickel, copper, and mica. Some of the pre-Cambrian sedimentary rocks contain rich iron and manganese ores. Paleozoic sedimentary rocks are important sources of coal, oil, phosphate, salt, and iron ore. Tin, copper, tungsten, lead, zinc, gold, and silver are the most common ores associated with moderately deep-seated igneous rocks of the Hercynian mountain belts. Mesozoic sedimentary rocks are important sources of oil, coal, phosphate, and low-grade iron ore. Silver, gold, lead, zinc, and copper are the chief metals associated with moderately shallow intrusive rocks such as characterize the Laramide mountain belt. Cenozoic sedimentary rocks contain oil, manganese, phosphate, sulphur, and low-grade coal. Cenozoic intrusive and volcanic rocks that are later than the Laramide revolution are in many places related to deposits of gold, silver, mercury, antimony, and tungsten. Thus, an appreciation of the general distribution of these rock groups throughout the world prepares us for the distribution of the important ore deposits and suggests the types that may be found in the future in given regions.

World Geology

Except where pre-Cambrian rocks have been engulfed by later up-welling magma, it is plain that rocks of this age must everywhere underlie later sediments. Where these sediments have been swept away by erosion, pre-Cambrian sediments and igneous rocks usually form the bed rock of the region. Extensive pre-Cambrian

terrains coincide with positive areas and with orogenic belts where the ancient rocks have been brought up in the center of folded welts in the earth's crust. Many extensive pre-Cambrian terrains are in part surrounded by belts of little-folded Paleozoic strata and in part by Hercynian mountains. The large pre-Cambrian areas are called shields, but if the pre-Cambrian rocks are covered by a thin veneer of sediment, they are known as platforms. There are seven such areas in the world: the Canadian shield, the Brazilian shield, the Fennoscandian shield, the African shield, the Australian shield, the Indian shield, and the Siberian platform. (See Figure 11.)

Pre-Cambrian rocks

Igneous rocks are especially abundant in the pre-Cambrian formations, and most of the area between the outcrops of igneous rock is occupied by thoroughly metamorphosed sediment, such as schist, gneiss, and slate. Some late pre-Cambrian rocks are relatively unmetamorphosed sediment and igneous rock, but the effects of heat and tremendous pressure are evident in nearly all but the latest of the pre-Cambrian formations. Mineral deposits of pre-Cambrian age are associated with certain types of igneous rock and are confined almost entirely to narrow zones within three miles of the edge of the intrusive body. In addition to mineral deposits related to magmas, the pre-Cambrian includes sedimentary ores, notably the pre-Cambrian iron ores. The richest and most extensive iron deposits in the world belong to this group and show marked similarities. Whether found in India, Wyoming, Michigan, Labrador, or Brazil, their appearance and general characteristics are startlingly similar.

Paleozoic rocks

The Paleozoic terrains of the world are generally found in belts that partly or completely surround the pre-Cambrian shields or platforms. The Hercynian mountains also show a rude parallelism with the edge of the pre-Cambrian shield areas; in places, they are found close to the edge of the pre-Cambrian, and at other localities there is an intervening span of little-folded Paleozoic rock between Hercynian mountains and a shield. These relations are well exhibited in North America, Europe, Asia, and Australia, but only to a slight extent in South America and Africa. (See Figure 11.)

In general, the Paleozoic sedimentary rocks are much less metamorphosed than are those of pre-Cambrian age; but within the Hercynian mountains, Paleozoic slate and schist are common. In

the bordering zones of upfolded rocks, the Paleozoic sediments are well lithified. Paleozoic clay is practically unknown, but both Paleozoic shale and Paleozoic slate are common. Abundant organic matter is first reported from sediments of Paleozoic age. Organic matter is more susceptible to metamorphism than are most rock constituents, and as a result oil is converted to gas and soft coal is converted to anthracite or to graphite by heat and pressure that would only change clay to hard shale or slate. In Paleozoic terrains, petroleum is confined to areas of but slightly folded rocks, and coal of different grades is found in regions of slightly folded and strongly folded strata. Intrusive igneous rocks of Paleozoic age are found in the Hercynian mountains, and thus the ore deposits of igneous affiliation are also localized in such regions. Unlike coal and oil, metamorphism of sedimentary deposits of phosphate, salt, and iron ore does not destroy their commercial value. Paleozoic sedimentary deposits of these substances are found in many places.

Mesozoic rocks

Mesozoic sedimentary rocks are found chiefly in broad belts between Hercynian mountains and shield areas and between Laramide mountains and shield areas. In North America, Mesozoic sediments extend southeast from northern British Columbia to the west side of the Gulf of Mexico. Mesozoic rocks crop out also in the coastal plains of the eastern United States from Florida to New Jersey. In South America, moderately continuous areas of Mesozoic sediments occur along the southwest border of the Brazilian shield and along the western margin of South America from Cape Horn to Colombia. Mesozoic sediments border the west coast of Madagascar and the east and northern coast of Africa and occupy a shallow basin in south-central Africa. A Mesozoic terrain occurs just west of the Hercynian mountains in Australia, lying between them and the pre-Cambrian shield. Between the Ural Mountains and the Fennoscandian shield, an embayment of Mesozoic sediments extends south and joins with an east-west zone of discontinuous areas of similar sediments in southern Europe. An extension of this belt is found in the Near East, but only a small part of the rest of Asia is covered by Mesozoic strata. These strata are found chiefly in northeastern Siberia, although a small area is also present in south-central China.

In most places the degree of metamorphism of Mesozoic sediments is decidedly less than that of Paleozoic strata. Mesozoic

clays and marls are common; Mesozoic slates and schists are rare. Most coal of Mesozoic age is of lower grade than is Paleozoic coal. In Paleozoic rocks, oil is confined to the most open type of folds; but in Mesozoic sediments oil is found in moderately sharp flexures. Sedimentary deposits of iron ore and phosphate are found in Mesozoic rock and some are moderately extensive. As a rule, however, Mesozoic sedimentary ore deposits are of lower grade than are comparable ones of the Paleozoic.

The Laramide mountains, which formed at the end of the Mesozoic era, girdle the Pacific Ocean and extend westward through the Malay Archipelago to southern Asia and across southern Europe and northern Africa to the Atlantic. The intrusive rocks of Mesozoic and early Cenozoic age are almost confined to this orogenic zone, and with them are associated the ore deposits of igneous affiliation.

Cenozoic rocks

Two types of Cenozoic rocks should be distinguished: 1) marine beds, and 2) fresh-water and subaerial deposits, commonly termed continental deposits. The marine sediments are almost confined to narrow discontinuous overlaps along the edge of the continent, except in South America and western Asia. Continental sediments are largely the wastage derived from Cenozoic mountains and occur in broad belts bordering the existing mountain ranges of the world. Here too should be classed the extensive glacial deposits left during the recent Ice ages in North America, northern Europe, and Siberia. The continental deposits contain little of value, but the Cenozoic marine sediments are the world's chief source of oil and also contain rich deposits of phosphate and manganese.

The marine Tertiary of North America is found in narrow basins in western California and in states bordering the Gulf of Mexico. Marine Tertiary is found along the north coast of South America from Nagal, Brazil, to Maracaibo, in western Venezuela, and is also found in the headwaters of the Amazon Basin. Much of Argentina also is covered with a thin veneer of marine Tertiary. In Africa some marine Tertiary occurs along the Mediterranean coast in northern Algeria and northern Egypt. It occurs only in two relatively small areas in southern Australia. Marine Tertiary strata are abundant and of great economic importance in the Malay Archipelago. A small but important belt of these rocks is found

in Burma and may be regarded as a continuation of the zone that crops out to the south and east in the Malay Archipelago. In Asia, a moderately broad belt of marine Tertiary sediments extends from the north-central Ural Mountains south to the Caspian Sea, where it turns northwest toward the Baltic Sea. However, west of the Caspian Sea the areas of Tertiary sediments are relatively thin and form only a small percentage of the total outcrop. Many irregular isolated areas are found in southern and central Europe.

Later Cenozoic orogeny followed nearly the same lines of weakness as those emphasized by the earlier Laramide mountain-making movements. Zones of active earthquakes and active volcanoes mark the Cenozoic mountain ranges. It is here that the ore deposits derived from magmatic emanations are found. Many of them are plainly related to partly eroded volcanoes and evidently formed within a few thousand feet of the surface of volcanoes that were active within the Tertiary period. Regions of Cenozoic volcanic activity are the chief sites of deposition of such epithermal ores as mercury and the rich "bonanza" type of gold and silver ore. Such regions also supply much of our antimony and tungsten.

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Part II

INDUSTRIAL MINERALS: THE MINERAL FUELS

CHAPTER 6

Coal

Uses of Coal

Coal is at present our greatest source of energy. It is the black chief of the mineral jinn who have given man Aladdin-like power. Coal smelts the metal for machines that have transformed our environment and made twentieth-century man master of the planet. It is on coal that the machine age chiefly depends for strength to do its daily work.

More than half the power produced in the United States must be credited to coal. Petroleum, its closest competitor in this field, yields one-third, natural gas a little more than one-tenth, and water power only about one-thirtieth of our energy requirements.(4) These proportions are not typical, however; all other industrial countries consume a far smaller percentage of oil. In those regions that have comparatively little coal and oil, the relative proportions of the different energy producers would vary correspondingly and the total would be only a small fraction of the 75,000 horsepower-hours per person produced annually in the United States.

Iron is the basis of our industrial civilization, but coke is the basis of the smelting industry. Although a little more than a ton of coal when converted into coke will smelt a ton of iron from good iron ore, at least two more tons of coal are required to convert this iron into steel and then into fabricated articles for the consumer. Such energy demands are best answered in a coal-producing region, and so the great manufacturing regions of the world concentrate near cheap, high-quality coal deposits.

Although the most important use of coal is for production of power, a substantial amount is used for heating our buildings and

homes. A citizen of the United States uses far more coal in this latter role than a citizen of any other nation. Coal enters into many articles of commerce by way of the chemical industry, which is one of the most appreciative users of the combustible black rock. Coal is also the chief raw material for the dye industries and for the manufacture of nylon and various plastics. In Germany, France, Japan, and Great Britain coal is an important source of gasoline.

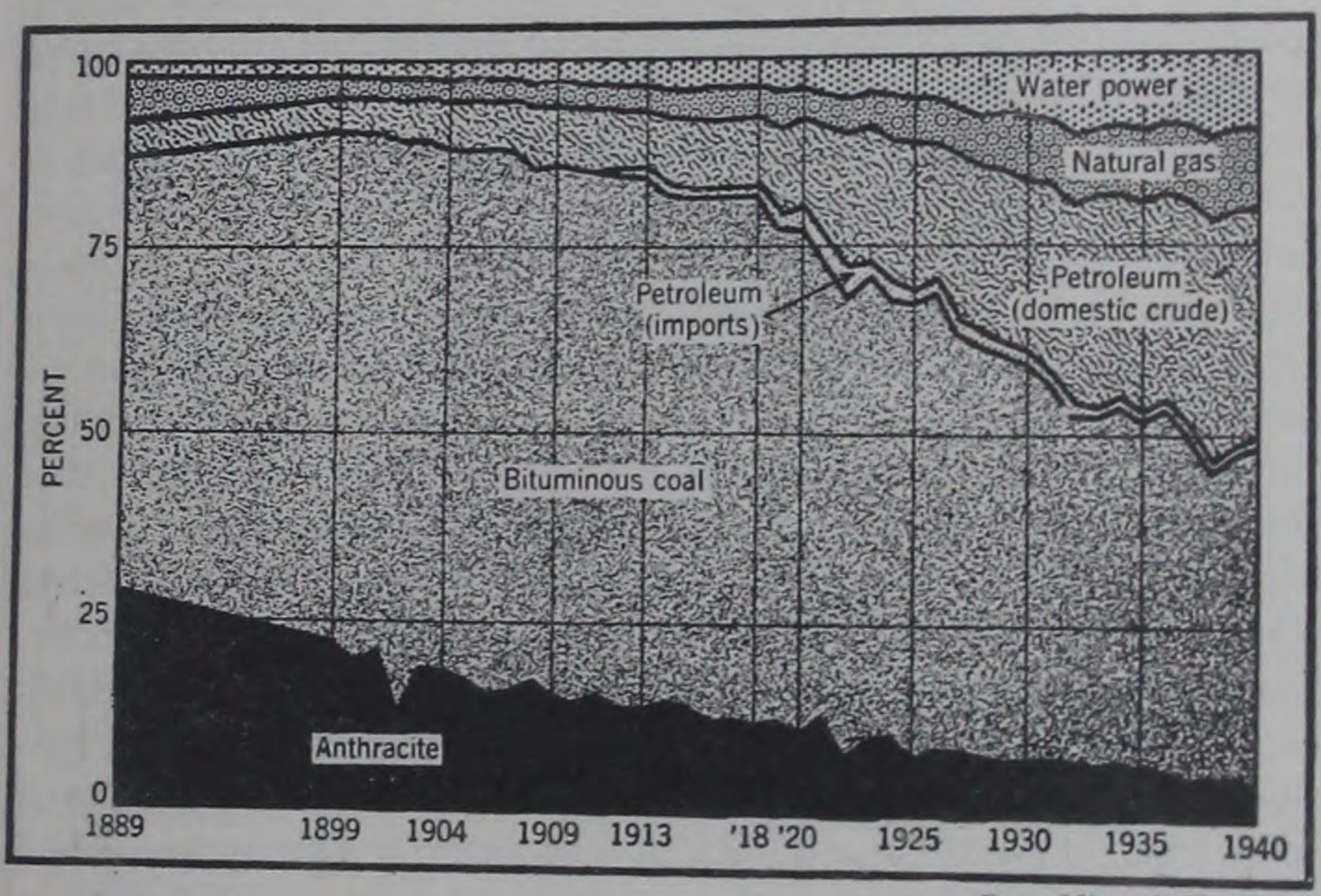
Even in the United States, where facilities for getting statistics on the mineral industries are unexcelled, it is difficult to break down figures for the consumption of coal into more than a few classes. Approximately 75 per cent of our coal is used for heat and steam power, 10 per cent for producing electricity, and 15 per cent for producing coke and by-products such as gas, ammonia, tar, benzol products, phenol, naphthalene, and other carbon compounds used in the chemical industry. Of the 430,724,000 tons of bituminous coal consumed in the United States in 1940, the amount used by various industries included 80,000,000 tons of locomotive fuel, 59,000,000 tons for pig iron manufacture, 53,400,000 for electric utilities, 3,421,000 for colliery fuel, 1,426,000 for bunkers and foreign trade, 65,583,000 for by-product coke ovens, and 4,803,000 for beehive coke ovens; all other uses totaled 152,700,000 tons.

Substitutes

Fuel oil, natural gas, water power, and wood or charcoal may be used for heat and power instead of coal when unusual conditions make them cheaper. Auxiliary sources of power of local importance include wind, tides, solar radiation, and animal power. Fuel oil and electricity generated by water power are much the most important substitutes for coal, but because of limitations of supply they can take care of only a small part of the total energy requirements of most industrial nations. Fuel oil competes most successfully in transportation. Hydroelectric power competes best within a radius of 200 miles or less from water power sites. At greater distances the cost of installing transmission lines involves such a large investment that the cost of amortization may make the electric power more expensive than current generated in a coal-burning power plant. Although fuel oil is being substituted for coal in the transportation industry, the rate of replacement has slackened and it is unlikely that any large gains will be recorded for fuel oil during the next decade. In 1940 the railroads of the United States consumed only 8,600,000 tons of fuel oil but took nearly

80,000,000 tons of coal. The continually increasing efficiency of engines has greatly reduced fuel consumption per unit of power, and thus, in a sense, engineering genius is a substitute for coal. Seven pounds of coal were needed in 1885 to generate a kilowatt-hour of electricity, but in 1940 only 1.37 pounds were required. As agents of conservation, engineers are in the first rank.

The actual proportion of the total energy requirements of the United States contributed by the various mineral fuels and water power varies from year to year, but a long-term trend is plainly observable. (See Figure 15.) A gradual decrease is noticeable



From Minerals Yearbook.

Fig. 15. Relative amount of energy furnished in the United States by different sources.

in the proportion credited to coal, especially anthracite, and the use of petroleum, natural gas, and water power shows a corresponding increase. The energy supplied by firewood in the United States is nearly equivalent to that produced from anthracite; muscle supplies about half as much as firewood; wind yields about one-twentieth of that derived from muscle.

Economics

For the most efficient extraction, coal should be in horizontal beds more than five feet thick within 500 feet of the surface, should contain little free gas, and should be underlain and overlain by strong rocks. Coal mining is highly mechanized in the United States,

moderately so in Germany and France, and least so in England. The degree of mechanization is reflected by the number of tons produced per man hour. The figure is highest in the United States where an average of five tons per man per day are mined. The investment in a large, thoroughly mechanized mine pays dividends only if the operation is nearly continuous. Such mines form the backbone of the eastern mining industry, and many of these properties are the so-called captive mines that operate in conjunction with other units of an integrated industry, such as with iron and steel plants or with railroads. The demand for heating coal is extremely seasonal in nature, and a substantial amount of the supply comes from small operators not burdened with a high overhead who can thus afford to close down in slack seasons. During the nineteen-thirties, still another factor tending to disrupt the coal industry was the appearance of so-called "bootleg" coal operations. As it is impossible for absentee owners to keep careful check on coal properties that are not being worked, many such properties have been exploited illicitly by local miners. It is estimated that nearly 4,000,000 tons of this stolen anthracite coal was marketed in 1940.

Most of the cost of coal at the mine is for labor, but most of the cost to the consumer is for transportation. The average cost of high-grade bituminous coal at the mine ranges from $1.75 to $2.00 per ton; but the retail sales price for such coal is approximately $8.00 per ton. Marine transportation is normally about six times as cheap as that by railroad. Coal near a seacoast will travel correspondingly farther than inland coal. Where freight on a railroad costs from one-third to two-thirds cent per ton mile, that carried on boats costs only from one-twentieth to one-tenth cent per ton mile for a haul of a few hundred miles or more.

The movement of coal between the United States and Canada illustrates the part played by freight rates in determining the sources of coal used in different regions. Canada produces only half of the coal she consumes, but Nova Scotia sends coal to New England. Both Alberta and British Columbia export coal to the northwestern states, but between eastern and western Canada coal moves from the United States northward across the border.

Technology

Not all coals can be used to make coke, but from suitable coal coke can be made by two methods. The beehive kiln requires coal containing about 32 per cent volatile matter and yields about 1,300

pounds of coke per ton of coal. The other 700 pounds is used in part for heating the coal, but most of it is wasted. By-product plants can use coal whose volatile content ranges from 20 to 33 per cent. A ton of coal yields 1,500 pounds of coke, 10,000 cubic feet of coal gas, 15 gallons of tar, 2 gallons of light oil, and 22 pounds of ammonium sulphate. In 1940, only 4.5 per cent of the coke produced in the United States was made in beehive ovens. Because of the economy of operating by-product plants with iron furnaces and steel mills, the three industries are becoming more and more integrated.

Synthetic gasoline can be made through the hydrogenation of coal; but the lubricants produced in this process are very difficult to dewax and are inferior to those made from natural petroleum. In all hydrogenation processes, the coal is heated, combined with hydrogen under pressure, and converted into a mixture of gasoline and oil that is distilled and separated into different fractions. In the Fischer process, the coal is gasified and then condensed. In the Bergius process it is powdered, mixed with heavy oil, and hydrogenated without gasifying. It is possible to use low-grade coals to make high-quality synthetic gasoline, but the cost is from three to five times the cost of producing gasoline from petroleum.

The amount of ash, sulphur, and "bone" (slaty country rock that accompanies coal), determines its *grade*. Much of the bone and some of the sulphur can be reduced by washing, but the character and amount of ash depends on the composition of the coal itself. Because of the difference in fusibility of the ash, coals with the same amount of ash may differ greatly in their suitability for use. If ash melts at a relatively low temperature, it quickly forms a glassy slag or clinker in the cooler part of a furnace. Coals with a fusible ash have little value for industrial power. The sulphur present in coal forms corrosive gases that attack the flues when the coal is burned, or it passes on to pollute the atmosphere.

A recent development has been the so-called "sink and float" method for separating coal from bone. Coal crushed to a size sufficiently small to free it from the accompanying bone is fed into a cone which tapers from about 15 feet in diameter at the top to about 2.5 feet at the base. A mixture of water and sand is pumped into the cone under a pressure of about 20 pounds per square inch. The combined sand and water mixture has a specific gravity of about 1.65, which is enough to allow the coal to float but is insufficient to float the accompanying bone. The coal is floated off as

a clean concentrate and the bone sinks to the bottom of the cone and is drawn off periodically. This method, developed by T. M. Chance, has proved to be much more efficient than was the older method of picking and washing coal.

Geology

Coal is a combustible rock composed of consolidated, carbonized, vegetal matter. Conditions favoring thick accumulations of plants uncontaminated by mechanical sediment are found in swamps on stationary or slowly sinking land of low relief. Unless covered by water or sediment and thus protected from the air, such material will be destroyed. Under a slowly thickening overburden, woody material gradually loses moisture; and when oxygen from the air is sealed out, the carbon content becomes more and more stable. Either heat or pressure tends to eliminate the volatile constituents and to increase the relative amount of nonvolatile or "fixed" carbon.

Somewhat different types of coal result from carbonization of different plant material, but the chief variations are due to differences in heat and pressure to which the plant stuff has been subjected. Peat may be regarded as the first step in a continuous series that leads ultimately to graphite. The peat that forms from the grassy moors in north country swamps is different in character from the peaty accumulations at the bottom of the cypress swamps of the southern United States (such as that shown in Figure 16), and the coal derived from these peats would have different characteristics.

Much has been learned about the transformation of organic matter into peat in the Dismal Swamp of southern Virginia and northern North Carolina. At the present time, the peaty layer at the base of the swamp is from 1 to 20 feet thick, and the average thickness is about 6.5 feet. Osbon estimates that approximately 672,000,000 tons of peat underlie the 2,200 square miles of swamp.(6) This region may be regarded as a classic example of the preliminary stages of coal formation. The alternating sands and clays that underlie it indicate several recurrent periods of uplift and subsidence—and apparently slow subsidence is taking place today. Although parts of the swamp are dry in the dry season, most of it is continually under water. A heavy growth of trees and underbrush cloaks most of the flooded area, but locally there are patches of open water. Branches, leaves, tree trunks, seeds, and spores are continually falling into the water and sinking to the bottom as they become waterlogged. Wind-blown material such as spores, leaves,

Courtesy of Dow Baxter.

Fig. 16. Cypress swamp south of Memphis, Tennessee.

and seeds constitute a much larger part of the plant debris in the open stretches of water than in other parts of the swamp. Coal derived from material rich in spores includes cannel coal, noted for the long oily flame with which it burns.

Although a foot of ordinary peat may form in from five to ten years, it will shrink through loss of water to a layer but an inch or so in thickness. It is estimated that with favorable climatic conditions compact peat may form at the rate of about three feet per century. About nine feet of such peat would be required to form a layer of bituminous coal twelve inches thick; but the time required to metamorphose peat into bituminous coal cannot be stated.

Metamorphism depends only in part upon time. Some peaty material has been changed to coal within a comparatively short period of geologic time, but our best coals are the oldest ones. Depending on the degree of metamorphism suffered, a coal's *rank* is classified as lignite, subbituminous, bituminous, semianthracite, anthracite, and graphitic anthracite. "Brown coal" is a term used for lignite and subbituminous coal. Black coal covers the ranks intermediate between brown coal and anthracite.

As a general rule, the grade of coal increases with its geologic age. Almost no coal is found in beds as old as Devonian, but Carboniferous coals are abundant and are generally of excellent quality. With only rare exceptions, the Paleozoic coals are black coals. The Mesozoic coals generally range from subbituminous to semibituminous, but locally, where intrusions or strong folding has affected the formation, good anthracite coal may be present. Most Cenozoic coal is lignitic. Brown coal is almost a synonym for Tertiary coal.

Moderate folding of the beds improves the quality of the coal but increases the difficulty of extracting it. The rank of folded Mesozoic coals may be comparable to that of flat-lying Paleozoic coal, but the cost of mining the folded seams may be much higher. As the coal beds in the horizontal strata of the plains pass into the disturbed rocks of a folded mountain range, a progressive increase in the fixed carbon content of the coal takes place with a corresponding improvement in its quality.

Most of the coal in the northern hemisphere is found in the Carboniferous, Cretaceous, and Tertiary rock systems. In the southern hemisphere, the Upper Carboniferous and Triassic systems contain most of the coal. The oldest seams of commercial importance are found in the Upper Devonian rocks of the northern Soviet Union and Norway, and in a few deposits in the eastern United States.

Only a very small proportion of the world's coal is obtained from this system, however. The Lower Carboniferous or Mississippian system, as it is known in the United States, contains excellent coal in Virginia, Nova Scotia, Scotland, the Soviet Union, Spitzbergen, Manchuria, and Korea. The Middle Carboniferous or Pennsylvanian system supplies much of the world's black coal. Most of the coal mined in central and eastern United States and eastern Canada is of this age. So is that in the important coal fields of England, Holland, Belgium, France, Germany, Silesia, and the Soviet Union. Upper Carboniferous or Permian coals are found in India, North China, Australia, and Africa. Triassic coal is found locally in the eastern United States, and the Triassic system also carries coal in Hungary, Austria, South Africa, China, Japan, and Australia. The Jurassic system carries excellent coal in China and Korea but is of minor importance elsewhere. Nearly all of the coal in the western United States and Canada is Cretaceous or early Tertiary. Thick seams of Upper Cretaceous coal are exploited in central Europe, and commercial seams of Upper Cretaceous coals are present in Africa, Asia, Australia, and northern South America. The distribution of Tertiary coals is similar to that of Cretaceous coals, but the average rank is lower.

Coal Fields of the World

The major part of the world's coal lies in the lands that border the north Atlantic Ocean; the remainder is scattered throughout the world. (Figures 17–19, 21–23.) Coal reserves of the various countries have been estimated; but for most of the coal-producing countries, the figures for the reserves are of such astronomical proportions that their repetition means little.(1) Thus, the statement that the United States has reserves of 3,500,000,000,000 tons and that Canada possesses reserves of more than 800,000,000,000 tons means only that coal can be mined at the present rate for many centuries. Of more importance than the reserve is the geology, thickness, and grade of coal and its accessibility to transportation.

The United States

The United States is producing more coal than any other nation in the world. Some 65 per cent of her 500,000,000-ton output in 1940 came from the Appalachian coal fields of Pennsylvania and West Virginia. Coal is produced in several other Appalachian states, but in no others does the amount approach that of these two.

As shown in Figure 17, the Appalachian coal field extends from Pennsylvania southwest to Alabama and in general follows the western side of the Appalachian Mountains. It is undoubtedly the most valuable coal field in the world and is the backbone of America's greatest industrial region. The coal ranges in rank from bituminous to anthracite, and nearly all is of Middle Carboniferous age. However, a moderate amount of Lower Carboniferous and Triassic coal is mined also. The bituminous coal occurs in flat-lying or slightly folded seams and is commonly from four to ten feet thick. It is easily mined, and the output averages five tons per day per man. Its enormous industrial value is due in large part to the presence of much excellent coking coal.

The anthracite field of eastern Pennsylvania is one of the most valuable mineral resources in the world and the chief source of anthracite in the western hemisphere. Prior to 1932, the value of anthracite coal mined in eastern Pennsylvania yearly was larger than the value of the combined output of the world's gold, silver, and lead. The coal is of Middle Carboniferous age and occurs in faulted complex tight folds; but as the major seams are from six to fifty feet thick, it is easy to understand why they constitute the most valuable coal beds known. Nearly all of this hard coal is used for domestic heating purposes. For many years these coal resources have been entirely in the hands of eight companies. The increasing use of fuel oil for domestic heating has cut into the monopoly formerly enjoyed by the anthracite producers. The competition has been reflected in a steady decline in production of anthracite during the past ten years. (See Figure 15.)

Our second most important coal field is in the Illinois basin. Illinois is the third largest producer in the United States, contributing about 10 per cent of our total. The coal occurs in flat-lying beds of Middle Carboniferous age which are close to the surface over extensive areas. Many of the mines can be exploited by open-pit methods at a very low cost. Much of it is excellent grade bituminous coal, but comparatively few areas in Illinois contain substantial amounts of coking coal.

The Midcontinent field extends from western Missouri to central Iowa. It contains a good grade of bituminous coal of Carboniferous age, but production is not large.

The Cretaceous and early Tertiary coals found in the western United States range from lignite to subbituminous in most places; but locally the beds have been metamorphosed by folding or intru-

sions, and higher-rank coals are present. Several of the Rocky Mountain states produce a few million tons of this coal annually. All of this coal is consumed locally.

Tertiary coals of low rank are present in Texas in large quantity, and in the north central part of the state subbituminous to bituminous coal of Middle Carboniferous age is present. However, the coal fields in Texas seem unlikely to become the center of important industrial regions.

The Pacific Coast is notably deficient in good coal. California and Oregon have very little coal and Washington, although it boasts five coal fields, has none to compare with those of the eastern states. The coal is all of early Tertiary age and ranges from lignite to bituminous in most places; there is some anthracite as well, but it is low grade. The beds have been strongly folded and faulted, and locally some are cut by igneous rocks. The seams are thin and "dirty." A little coking coal is present, however, and in the uneconomic conditions that characterize war, it might be used as the basis of a smelting industry.

Canada

More than half of Canada's coal reserve lies in Alberta, but her most immediately valuable deposit is probably that in Eastern Nova Scotia. Here excellent coal of Lower and Middle Carboniferous age is found close to the coast in moderately folded beds ranging from three to thirteen feet in thickness. Much is of coking quality and is used to smelt iron ore from Newfoundland. It is also exported to the New England states.

The coal fields of Alberta and Saskatchewan are similar to those found to the south in the United States and, like them, are of lower quality than the Paleozoic coals of the east. British Columbia has several coal fields, and some of them contain Cretaceous and Lower Tertiary bituminous and coking coals of good quality. Many of the coal seams range from five to fifteen feet in thickness, and in a few localities coking coals of even greater thickness are known. Not all of the coal fields are readily accessible, however, but some of them, such as the coal fields on Vancouver Island, move their coal to market at a very low cost.

South America

Colombia has several coal fields that are as yet but little developed. The coal is Cretaceous in age, of bituminous rank, and

some of it is coking coal. Reserves are estimated at nearly 30,000,000,000 tons. Coal is widely distributed in Venezuela but is not exploited. Brazil has a small coal-mining industry centered in the southern part of the country where a moderately extensive area is underlaid by Upper Carboniferous coal. Most of the coal, however, contains a substantial amount of bone, sulphur, and ash, and must be carefully picked and washed before it is in a marketable form. Chile is one of the chief producing countries in South America and has reserves estimated at about 2,000,000,000 tons. Her annual production is less than 2,000,000 tons; most of the coal is of inferior quality, but it would be classed as bituminous rank. It is of middle Tertiary age and occurs in Arauca and Concepcion. Peru has coal reserves comparable to those of Chile, and the rank ranges from subbituminous to anthracite. Both Cretaceous and Tertiary beds are mined in the Peruvian Andes. The largest coal field is near Cerro de Pasco, Peru's greatest copper mine. Since a substantial amount of the coal known in Peru is of anthracite grade, it is possible that this country will become an important producer in the future. In 1940, however, the production was small.

So far as is known, the coal resources of the other South American countries are unimportant.

Great Britain

Great Britain is the world's third largest producer of coal and led the world for a considerable period in the nineteenth century. In the early nineteen-thirties both Germany and the United States far surpassed her output. Great Britain has long been famous as the world's premier exporter of high-quality black coal. The abundance of cheap bituminous coal was chiefly responsible for Great Britain's commercial hegemony during the nineteenth century.

It has often been pointed out that Great Britain is exhausting her coal reserves faster than is any other large commercial nation. However, her reserves of commercial coal above a depth of 4,000 feet approximate 150,000,000,000 tons. Since a little more than four years is required to take out a billion tons of coal, her reserves should be adequate for at least five or six centuries. The beds in some of the coal fields are moderately folded, and mining proceeds at ever greater depths. More than 70 per cent of the cost of mining in England must be charged to labor, and the increasing depth of the mines is a factor in cutting the position of British coal on the

export market. The narrowing margin between selling price and producing costs has been reflected in a decreasing standard of living for the British coal miner.

The chief coal fields in the United Kingdom include central Scotland west of Edinburgh and districts south of Newcastle, east of Liverpool, and west of Cardiff, Wales. The Cardiff field is the greatest exporter of coal in the world. This area is noted for its excellent high-rank black coal, which ranges from bituminous to semianthracite. Much of it is a good coking coal. The gently tilted Carboniferous beds contain several different coal seams, but the strata are broken by many faults. Although the coal beds are gassy and thin, they are more easily worked than are those of most other British fields.

France and Belgium

Middle Carboniferous coal ranging from bituminous to anthracite is found in northern France near Valenciennes. The beds are rather thin, steeply inclined, and strongly faulted. The quality of the coal is excellent, but because much of it lies at a considerable depth below the surface, the cost of mining is moderately high. The Namur field in central Belgium contains the eastern continuation of these coal measures and furnishes most of Belgium's production. Like the French field, the structure is complex, and mining is expensive. The deepest coal mine on record is in the Namur basin. This bed had attained a depth of nearly 4,000 feet in 1940. Both coking and steam coal are present. The coal districts of Belgium and western Germany connect with those of the Netherlands, which have similar characteristics. France obtains relatively little coal from her other fields, such as the Point de Moussin field, the southwestward continuation of the important Saarbrück field.

Germany

Germany produces more coal than any other nation except the United States. It has large reserves of both black coal and brown coal. The most important districts include the black coal districts of the Ruhr, Aachen, the Saar, Upper and Lower Silesia, central Germany, and the brown coals of Prussia, Saxony, Bavaria, and Hesse. About two-thirds of Germany's black coal comes from the Ruhr district and about one-sixth comes from Silesia. The remaining sixth is supplied largely by Aachen, Saar, and Saxony. A little more than half the lignite comes from Saxony, slightly more

than a third from the Rhine province, and Lower Silesia contributes about one-fifteenth.

The coal beds of the Ruhr basin, or the Westphalian field, as it is also known, are of the same age as those lying on the west side of the Rhine River but, unlike them, the Ruhr beds are only gently folded and but little faulted. Most of the individual seams of black coal are thin or only moderately thick, but thirty-two mineable coal beds are present in some parts of the basin and have an aggregate thickness of 190 feet. The district is noted for the excellence of its high-volatile bituminous coals suitable for making gas. The coal is cheaply mined and, as a consequence of the low cost and high quality, this district has become the center of German heavy industry.

Second only to the Ruhr in importance are the coal fields of Silesia. Both coking and steam coals of good grade are found in this region. The seams are thick and lie at shallow depths. They are slightly inclined and are little faulted. This combination of favorable conditions allows cheap mining and makes this region of Carboniferous coals the center of a rich industrial area.

The brown coal beds of Germany are both extensive and thick. In some places, the coal seams are more than three hundred feet thick. Eighty-five per cent of the coal is mined by open-pit methods and as a result can be marketed at a very low cost. This coal is the source of much of Germany's synthetic gasoline. The average thickness of the brown coal in the surface mines is sixty-five feet, but the average thickness throughout the Rhineland is three hundred feet. Germany normally consumes about two-thirds of her coal and exports about one-third as coal or coal products.

The treaty of Versailles divided most of the eastern coal fields between Czechoslovakia and Poland, but Germany was given much of the brown coal area. Poland received only a small part of the Silesian coal fields by the treaty of Versailles, but the plebescite in 1922 gave her the area just north of Czechoslovakia, which included a part of the richest mining district. Seventy per cent of the total production of Czechoslovakia came from the Osgrava coal field just south of the Polish border. After the annexation of the Sudeten area by Germany in 1938, Poland, following Germany's example, extended her boundaries southward to take from her now helpless southern neighbor this valuable coal field with its high-quality coking coal and 1,300 square kilometers of highly industrialized, densely

populated country. Poland normally exported about one-third of her total production of approximately 30,000,000 tons.

Although some coal occurs in nearly every country in Europe, nearly all the north and south European states are deficient in this mineral and import from their more fortunate rivals.

The Soviet Union

The coal reserves of the Soviet Union are comparable with those of the United States and are estimated at more than 1,500,000,000,000 tons. However, 91 per cent of it lies in Siberia and has been little developed. Most of the Soviet coal is of Carboniferous age and ranges from bituminous to anthracite in rank; but large areas of brown coal are known, and in some of them mining is going forward.

The Donets basin just north of the Sea of Azov contains coking coal and semianthracite. It is the center of the Soviet Union's heavy industry. This district has supplied most of the Soviet's past output, but for several years its production has fallen short of the demand placed upon it by the rapid industrial expansion of the region. Although the Donets basin contains 135 coal seams, mining is expensive and difficult because the beds are much folded and faulted. However, the presence of the Krivoi Rog iron ore makes this basin a natural economic unit and one that should become of increasing importance.

Large areas are underlain by coal in the vicinity of Moscow, but the quality of the coal is not high where it is accessible and the coal field is little developed. East of the Ural Mountains, the most important coal districts are found at Kuznetzk and at Sudensk. Coal fields are being developed in the Caucasus, Kazakstan, central Asia, and the Far East.

Although the Soviet Union has an abundance of hard coal of excellent quality scattered through the vast stretches of Siberia, she has been meagerly endowed with coking coal. In only a few places is coking coal now known sufficiently close to iron ore to allow the efficient development of an iron and steel industry.

India

Several structural basins contain Carboniferous coal in northern and central India. It is estimated that about 4,500,000,000 tons of easily accessible, high-quality coal is available in the Indian coal

fields and that about one-third of it is of coking quality.(10) Most of this reserve and most of India's output is credited to the Bihar and Orissa coal fields in northern India. The coal seams commonly range from one to twenty feet in thickness and occur in flat-lying or gently sloping beds that can be cheaply mined. The fortunate juxtaposition of Carboniferous coal and pre-Cambrian iron ore in northern India permit the production of the lowest cost pig iron in the eastern hemisphere. It is probable that northern India will become increasingly industrialized as these two resources are exploited and the tremendous internal market afforded by the densely populated peninsula develops.

China

The coal fields of China are scattered over a wide area and contain much excellent hard coal; but reserves of coking coal are comparatively small. Almost all of her developed coal fields are in Manchuria and north China, and this latter area normally supplies about two-thirds of her total production. The Triassic and Jurassic coals of south China are of lower rank in most places than are those of north China, but locally they have been folded and metamorphosed into high-rank coals. In such places, the difficulty of mining the steep broken beds offsets in some degree the increase in value due to their higher rank. The large reserves that exist in Hunan, Szechwan, Shensi, Yunnan, and Kweichow lay almost completely unopened until the Japanese invasion led the Chinese to exploit coal deposits distant from the coast. In 1940 the production of coal mines in south China under the Chinese national government was 5,716,000 metric tons, approximately one-third the total output for China. The coal mines of north China and the Yangtze River valley were expropriated from their Chinese owners by the invading Japanese, and approximately a third of the coal produced was exported to Japan, Korea, and the Kwantung leased territory.

Japan

Japan has many small coal fields, but except for those of Ishikan, the seams are not thick. Triassic, Jurassic, and Tertiary coals are present and range from lignite to anthracite. Many of the coal fields have been folded, faulted, and intruded by igneous rocks, and mining conditions are difficult. Most of the coal comes from northern Kyushu, but a substantial amount is also mined in Hokkaido. The Ishikan coal fields contain as many as 150 lenticular seams of

Tertiary bituminous coal. In spite of the energy of the Japanese, the coal fields of the island empire have long been inadequate to supply the industrial requirements. The desire to satisfy these demands largely motivated the acquisition of the coal fields of north China and Manchuria. The total Japanese reserves are estimated at a little over 6,000,000,000 tons, less than 1 per cent of the amount credited to China.

Africa

Most of Africa is barren of coal, but several fields are known in the southeastern part. The most important commercial coal fields are those in the Union of South Africa. The coal is of Upper Carboniferous and Triassic age and occurs in nearly flat-lying beds commonly from four to fifteen feet thick. The reserves are said to be large. About 40 per cent of the production is obtained near Pretoria, but there are several other producing areas. Much of the coal goes into the bunker trade. Coal fields are also known in Nigeria, Madagascar, Rhodesia, and the Belgian Congo; but production from these areas has been small.

Oceania

The East Indies and the Philippine Islands contain substantial amounts of brown coal of Tertiary age but are notably deficient in coking coals and bituminous steam coals.

Australia contains large reserves of high-rank coals and undoubtedly has the most valuable coal fields in the southern hemisphere. The thickest beds of black coal known have been discovered in Australia. The attitude of the coal strata varies from horizontal to steeply inclined, but mining costs are not unusually high. Mining has centered in southeastern Australia near Newcastle and Sydney in New South Wales. This province commonly contributes about 85 per cent of the continent's black coal production. The coal fields of Queensland to the north produce more than a million tons annually of good clean bituminous coal. The coal resources of Victoria at the southwestern tip of Australia include both black and brown coal, but they are little used. This province yields all of the brown coal produced in Australia. Western Australia contains only two small coal fields, one in the Fitzroy River basin in the northern part of the continent and the other south of Perth in the extreme southwest. The latter is the only one that has pro-

duced any coal. The coal is a noncoking subbituminous variety of low grade.

Production and Consumption

The annual production of coal for the world is about 1,500,000,000 tons. The proportion contributed by the chief industrial countries is revealing: the United States 25 to 30 per cent; Germany 20 to 30 per cent; Great Britain 16 per cent; the Soviet Union 10 per cent; France 3.5 per cent; Japan 3 per cent; Poland 2.5 per cent; Belgium 2 per cent; India 2 per cent; China 2 per cent, and the rest of the world about 10 per cent. Good cheap coal is the basis of industry; the list of consumers in their proper order is the same as the list of the chief producers. The production of coal during certain representative years is shown in Table XXVI in the Appendix.

Only 15 per cent of the world's coal is exported; of this 15 per cent Great Britain contributes about 6 per cent, Germany about 3 per cent, the United States about 2 per cent and Poland 1.5 per cent. Most of the export coal from the United States goes to Canada. Great Britain and Germany normally compete for the coal business of southern Europe. The coal of Great Britain is much in demand by ships for bunkering. Poland's best customers were Austria, Czechoslovakia, and Yugoslavia.

The coal production of Great Britain has remained relatively constant for many years, but that of Germany increased steadily from 252,000,000 tons in 1920 to 430,000,000 tons in 1939. Although more than half her output is in brown coal, her production of bituminous coal in 1940 was almost as large as that of Great Britain. The Soviet Union shows an even more striking increase. In 1920 her production was only 7,700,000 tons; by 1930 it had climbed to nearly 40,000,000 tons; in 1939 it reached the surprising figure of 133,000,000 tons. This steady increase tells much of the story back of the industrial power that kept the Soviet army successfully opposed to the German war machine during the winter of 1941–1942. Although most of the coal is in the Donets basin north of the Black Sea, coal fields in western and southern Siberia contributed an increasing amount of fuel to the developing heavy industries near by.

The excellent coking and steam coal of India, which stands in close proximity to high-grade iron ore, is the basis of a domestic iron and steel industry that consumes much of the 28,000,000 tons of coal produced. Little has been exported. Japan imports coal

from Manchuria, China, and Indo-China and has developed her own meager coal fields to the limit. Her conquest of Manchuria was directed in part toward attaining more coal, but the developments were disappointing. Her move into north China, however, was more successful.

Commercial and Political Control

Commercial and political control are identical for almost all of the world's coal fields. Prior to the first world war, German capital controlled coal mines in Australia and others of the Allied countries. The loss of such properties during the war discouraged investments in this type of mineral deposit in countries that were commercial rivals.

National Policies of Principal Industrial Countries

For the United States, coal means an industrial economy. Its cheapness and proximity to the Atlantic Ocean suggest commercial competition in foreign markets, but the internal market is very large. Great Britain has mined out her cheap, shallow coal. Some of the mines are now three thousand feet deep and some of the coal beds that are mined are only eighteen inches thick. Her gradual loss of export trade for a time caused her to pay a subsidy of four shillings per ton to exporters of her coal! British coal mines have been slow to adopt mechanization, and costs have been higher than for her competitors on the continent. This has had an effect on other industries and has raised all of the marginal producer's social and political problems. Germany has competed successfully for some of England's former markets, but two-thirds of her coal is consumed by her own industries. The abundance of coal and the lack of oil has led to building many hydrogenation plants for the manufacture of synthetic gasoline and oil. The need for a great industrial machine to carry out her war aims naturally directed Germany's attention to the possibilities of acquiring coal and industrial areas in neighboring countries. Japan, relatively poor in coal, exhibits the same motivation.

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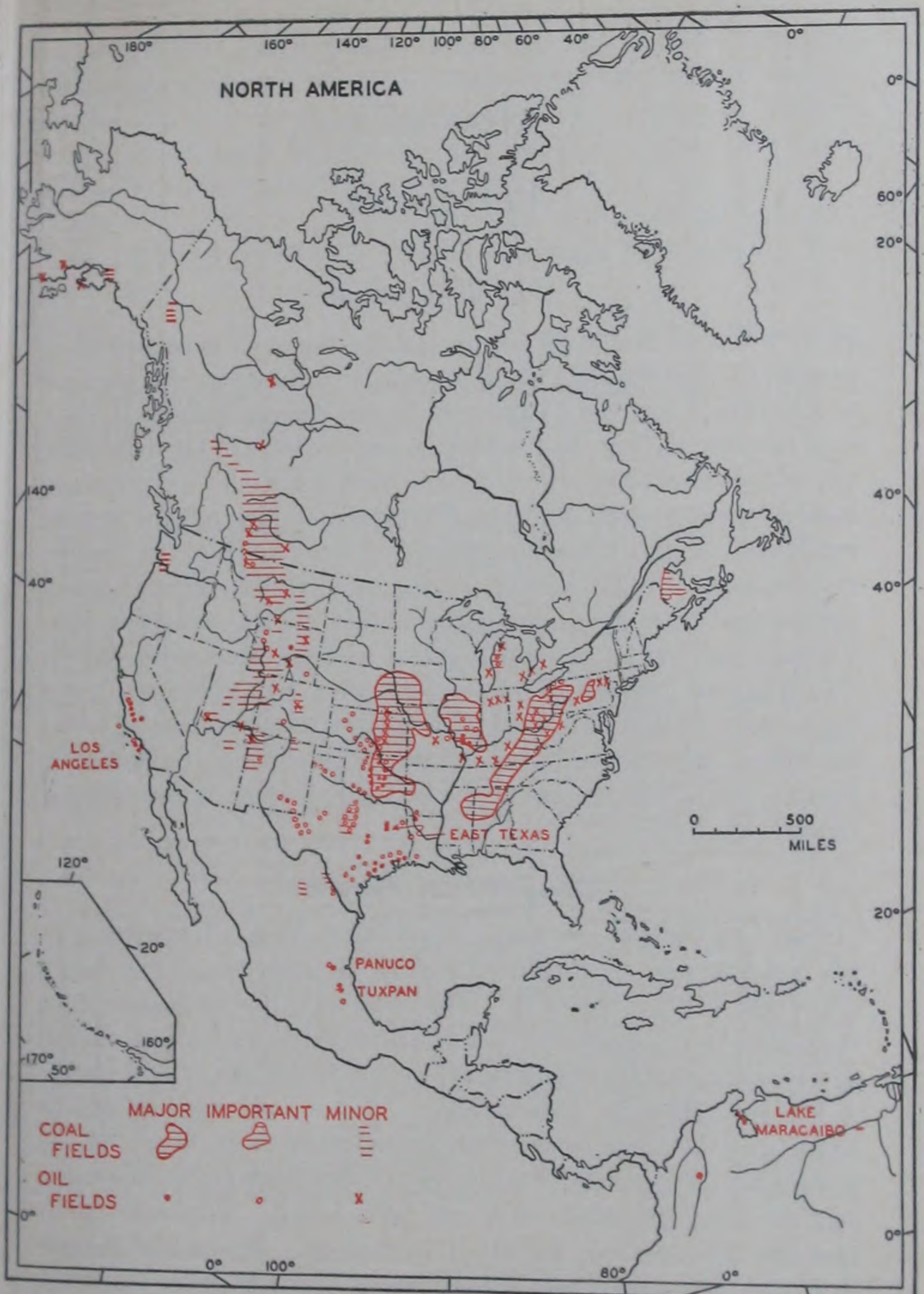


Fig. 17. Distribution of coal and petroleum in North America.

CHAPTER 7

Petroleum

Uses of Petroleum

In the United States, 45 per cent of the crude oil is converted to gasoline, 37 per cent to fuel oil, 4 per cent to lubricants, 4 per cent to kerosene, 5 per cent to gas used in the refinery stills, and 5 per cent to coke, asphalt, and miscellaneous products. All told, more than a thousand products are derived from crude oil. They include such diverse things as synthetic rubber, anesthetics, oils for making candy and cosmetics, insecticides, gas for ripening fruits, ointments, disinfectants, paraffin, varnish constituents, metallurgical reducing agents, timber preservatives, battery fillers, roofing materials, electrodes, nasal sprays, and many others that are used every day by the American public with no suspicion that they were once just a black blob of crude oil. Fuel oil is finding increasing use as a fuel for firing both stationary and motile steam plants, especially in boats. The use of furnace oil for domestic heating is also growing rapidly.

Substitutes for Petroleum

Coal and fuel oil are competitive steam fuels. However, it is not a simple matter to convert a plant designed to use one into a plant that will use the other. The short-time fluctuations in price thus have only a small effect on substitution of coal for fuel oil, but any long-time trends would be reflected in the design of new plants. A few vegetable oils, such as castor oil and rope seed oil, can be substituted for some of the lubes produced from crude oil, but no thoroughly satisfactory substitutes for the high-grade lubricants derived from petroleum have yet been found. Synthetic motor fuels can be made from coal and from shale oil. Production of gasoline from coal costs about four times as much as from crude oil. Shale oil may be made at about fifteen cents per gallon, but the cost of producing gasoline from crude oil in the United States is only about five cents per gallon.

In Europe, where the price of gasoline ranges up to nearly a

dollar a gallon in normal times, much petroleum is saved by using substitutes whose use would be uneconomic in the United States: alcohol and compressed natural gas are used in specially designed internal-combustion motors, and charcoal and coal are employed in steam-driven trucks.

The relative amount of power supplied by the mineral fuels and water power in the United States has already been noted. (See page 117.)

Technology

The technology of petroleum may be considered under the headings, production, transportation, and refining.

Production

Almost all petroleum is produced from wells, but a small amount comes from mines in Germany and France. A shaft is sunk through a reservoir rock and passageways are driven out under the oil-bearing bed. Holes are drilled upward to drain the oil, and brine is pumped into the oil sand at the ends of the passageways most remote from the shaft to force the oil toward the drainholes. (6)

Oil wells are drilled either by the "standard rig" or the "rotary rig." The standard rig uses a cable to which is attached a heavy bit that is alternately raised and dropped, pulverizing the rock at the bottom of the hole. From time to time the bit is hoisted to the surface and the sludge at the bottom of the hole is removed. This method is relatively slow, but it is cheap and is used chiefly in well-lithified rocks. The rotary rig uses an abrasive drill bit such as that shown in Figure 20, which is rotated continuously in a hole full of water. The cuttings are flushed to the surface by an upward current that is maintained by supplying water under pressure at the bit. The rotary rig drills rapidly and is extensively used in soft formations. Holes have been drilled as much as 2,500 feet deep in a single day. It is now possible to drill holes to a depth of more than 15,000 feet with a rotary outfit.

Transportation

In the order of increasing cost, the carriers of oil are: tanker, pipe-line, railroad, and truck. Trucks are used chiefly for moving refined products; the other three carry both crude and refined petroleum. The extensive use of pipe lines has engendered some unique problems of protection from pilferage. (12)

Fig. 18. Distribution of coal and petroleum in South America.

Fig. 19. Distribution of coal and petroleum in Europe.

Refining

Petroleum is a mixture of many different oils in which are dissolved paraffin, asphalt, and other hydrocarbons that would be solid at ordinary temperatures if separated out.

Courtesy Reed Roller Bit Co.

Fig. 20. Ready to lower bit. A typical rotary bit of the type used in deep holes.

In addition to these substances, petroleum as it comes out of the well carries dissolved gases and some emulsified brine. The complicated problem of separating these many constituents requires all the skill of a chemical engineer, but the basic principles used in refining oil are relatively simple. The petroleum is heated and most of its components are differentially volatilized with or without being made to take part in chemical reactions, and then separately condensed. The cheapest and least efficient method of refining oil is the "straight-run" or fractional distillation process. Petroleum is heated slowly at ordinary or reduced pressure and the distillates that come off between certain definite temperatures are kept separate. Gasoline vaporizes first and is followed successively by kerosene, gas oil, lubricants, paraffin wax oils, fuel oils, and asphalt, leaving only a small residue of petroleum coke. Straight-run gasoline constituted a little less than half the gasoline produced in the United States in 1940. Virtually all of the rest was produced by "cracking."

In the cracking process distillation is carried on under pressure. Complex hydrocarbon molecules are cracked into smaller ones; during this process some lose hydrogen and some become richer in this important constituent. The gasoline fraction, which consists of relatively small simple hydrogen-rich molecules, thus increases. This process requires a more elaborate plant than does straight-run gasoline; it is somewhat more expensive but much more efficient. About 60 per cent of the crude oil is converted into gasoline in the cracking process and only about 25 per cent in the straight-run.

A still more complicated refinery is the hydrogenation plant. It is similar to the cracking still but has to withstand higher temperatures and pressures. Hydrogen is introduced into the cracking chamber, where it combines with the cracked complexes and thus increases the gasoline fraction to any desired amount. It will be too expensive to be profitable in North America, until the price of gasoline rises materially. In 1940 there were only two such plants in the United States.

Improvements in refining are constantly being made. Two recent innovations promise to become increasingly important. Polymerization stills convert the small molecules of simple hydrocarbon gases into the larger and slightly more complex ones of gasoline, a process that is just the reverse of cracking. Catalytic agents are chemicals that promote certain reactions without themselves being

Fig. 21. Distribution of coal and petroleum in Africa.

Fig. 22. Distribution of coal and petroleum in Asia.

used up in the process; such agents have been found for expediting the cracking process and increasing the yield and are used in catalytic cracking.

Prior to 1905, gasoline was less desired than kerosene, and many refiners threw away all gasoline that could not be added to their kerosene fraction. Although cracking plants were installed as early as 1910, they were unimportant till 1920. Since that time they have become increasingly popular.

The average gasoline yield of all crude oil refined in the United States was 10 per cent prior to 1910, and was 45 per cent in 1940 when our crude oil was converted into the refinery products indicated in the accompanying table.

TABLE V

PROPORTION OF CRUDE OIL CONVERTED INTO DIFFERENT REFINERY PRODUCTS IN THE UNITED STATES IN 1940*

Gasoline	43.1	Road oil	0.6
Fuel oils	38.6	Coke	0.6
Kerosene	5.7	Unfinished	0.4
Still gas	5.5	Other	0.3
Lubricating oil	2.8	Wax	0.1
Asphalt	2.3		
		Total	100.0

* 9, p. 972.

Economics of Petroleum

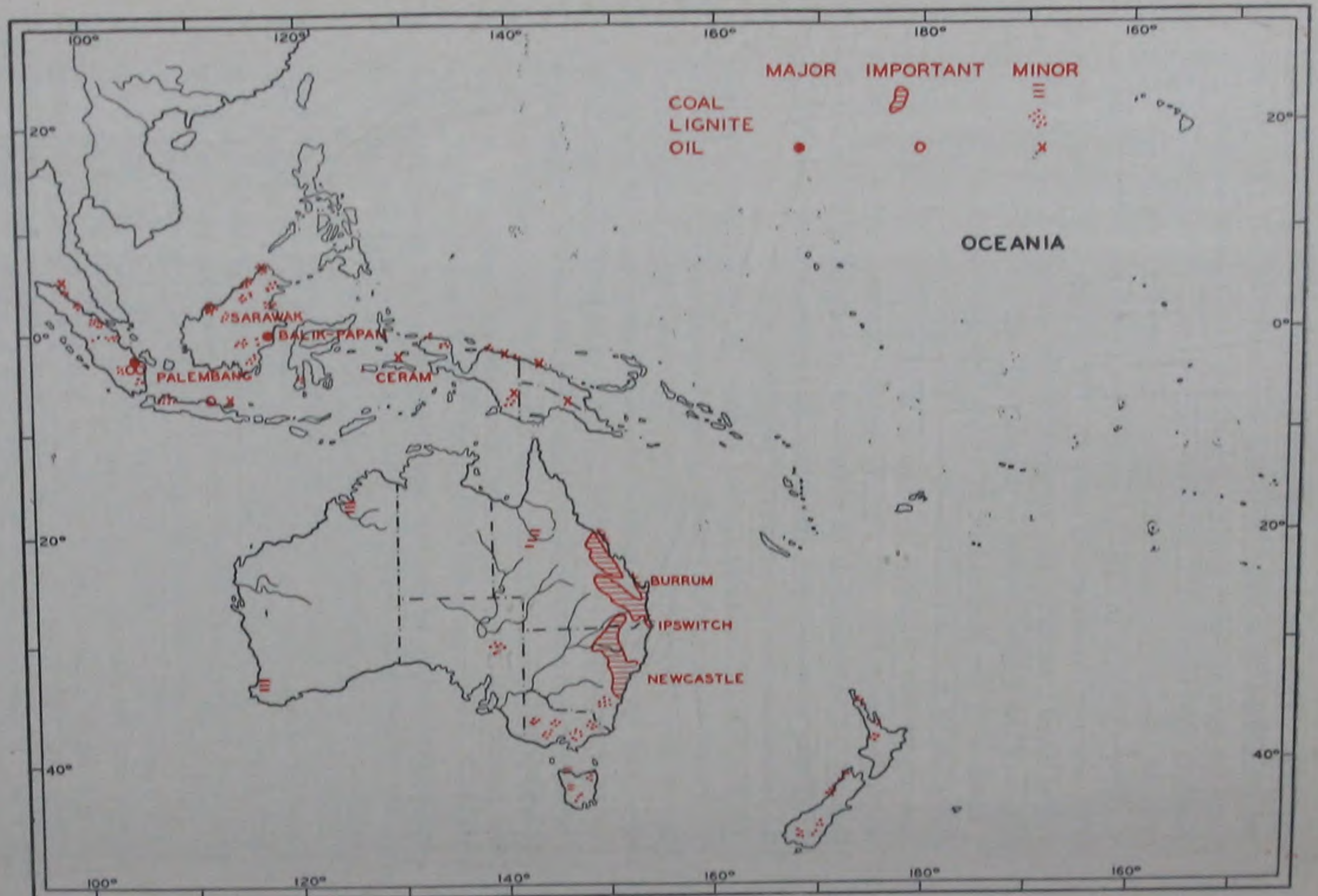
Oil is one of our most quickly depleted natural resources and there is no reuse of "scrap." Because of the speed with which it can be withdrawn, it is essential to find new oil fields each year to keep up reserves of oil that would otherwise be diminishing. Most of the oil structures that are easily recognized have been tested, and methods of finding less obvious ones are relatively expensive. Elaborate geophysical equipment is used to study the physics of the earth's crust in regions that are thought to carry oil. The results are interpreted in terms of the probable geology, and test wells have been drilled 15,000 feet deep in California on the strength of deductions thus made, although evidence for oil accumulation was lacking at the surface. The cost of a single geophysical prospecting crew commonly ranges between $10,000 and $20,000 per month, and the cost of a deep test well is from $100,000 to

$250,000. Thus the search for new oil fields is becoming more and more the work of a large, well-financed organization. For several years the rate at which new oil fields have been discovered has been less than that required to maintain oil reserves. It is quite possible that the rate of discovery will again increase when stable economic conditions promise to exist for some time in certain foreign regions. Only one non-American oil concern, the British- and Dutch-controlled Shell Company, has approached the success of the oil companies of the United States in discovering new oil fields.

Because of the fluid nature of oil and the associated gas and salt brines, many unique problems exist. The movement of oil and gas from under one property to wells in adjacent land has been mentioned (on page 22). An equally serious problem is that of brine disposal. Contamination of streams or underground water supply is difficult to avoid, and the precautions required usually add a substantial amount to the cost of producing oil.

It has been abundantly proved that wells get the most oil from an oil sand when not too closely spaced and when they conserve the gas associated with the oil. Even under very good management, only from 40 to 65 per cent of the oil present can be produced. Wasteful methods may leave 85 per cent of the oil underground in a condition that makes it almost impossible to extract. Enactment of laws promoting good practice has been slow but steady in spite of the concern of many operators over the infringements of their "rights." Minimum spacing for wells, regulations for drilling procedure, prohibition of gas wastage, proration of oil production, and similar conservation measures are now written into law in most states. Even so, some new fields are overdrilled.

Many people fail to realize the finite character of an oil pool. Consider, for example, an oil field that covers one square mile. The total amount of oil present under this 640-acre area depends on the aggregate thickness of the oil sands, their porosity, and the degree to which the pore space is saturated. Using figures that would be quite reasonable for many Michigan fields—10 feet for thickness, 20 per cent for porosity, and 75 per cent for saturation, the amount of oil is readily calculated if we know that the volume included in a layer one foot thick having an area of one acre is equal to 7,760 barrels. Under one acre of the field there would be: 7,760 barrels times 10 (thickness) times 0.20 (porosity) times 0.75 (saturation) equals 11,640 barrels. If this oil is conservatively produced, it


MAJOR
IMPORTANT
MINOR
COAL
LIGNITE
OIL
OCEANIA
SARAWAK
BALIK PAPAN
PALEMBANG
CERAM
BURRUM
IPSWITCH
NEWCASTLE
100°
120°
140°
160°
180°
160°
20°
0°
20°
40°

should be possible to get between 5,000 and 6,500 barrels per acre; if overdrilled and inefficiently produced, about 2,000 barrels per acre might be the recovery. With the price at $1 per barrel, it is plain that the return per acre can only range from $2,000 to $6,500. Against this must be charged cost of drilling and casing the well, cost of production, royalties, overhead, and profits. Although a shallow well may cost only a few thousand dollars, most wells are now drilled several thousand feet before striking the "pay" and cost much more. In Michigan, for example, the wells in the central fields cost upward of $20,000 when completed and on the pump. Thus, any spacing of less than one well to four acres in the example above would result in an obvious loss. This loss would have to be multiplied by the number of wells in the field to get the loss for the entire pool. The loss occasioned by overdrilling in some of the Oklahoma oil fields has amounted to $70,000,000.

Geology of Petroleum

The entire philosophy of oil geology is related to the fluid nature of petroleum. The essence of this philosophy is that four conditions are required for the accumulation of oil: 1) a source rock must be present; 2) a porous and permeable reservoir rock must be available close to the source rock; 3) conditions of heat and pressure suitable for generating petroleum in the source rock must exist for a time; 4) an oil "trap" must be present.

Source rocks

Relatively shallow-water marine sediments are believed to be the source rocks for oil. Plant and animal remains carried into the sea by rivers, and the constant accumulation of dead marine organisms, contribute an appreciable amount of organic matter to sand and clay that settle out on the sea bottom. The tiny bodies of the vast horde of microorganisms that live near the surface, known as plankton, probably make up most of this organic deposit. It is not petroliferous when buried, but under suitable conditions of temperature and pressure in the compacting sediment, minute droplets of oil are generated through the source rock and, influenced by capillarity and compression, they move into more open spaces if any are available. If the source rocks are marine clays, they may be reduced by compaction to less than two-thirds of their original volume through the gradual reduction of the moisture content. In this

process, the liquid moves along temporary fissures to the surface or into stronger permeable beds such as sand or gravel. If oil is present, it moves along with the water. The strata recognized as source beds are commonly brown to dark-gray marine shales that have a characteristic fetid or bituminous odor. Dark-colored limestones with an unusually high percentage of organic matter are the next most important petroleum source rocks. The majority of petroleum geologists believe that sandstone and conglomerate are rarely source beds and that fresh-water deposits, deep-sea deposits, continental deposits, metamorphic rocks, and igneous rocks are never petroleum source rocks.

Reservoir rock

Any porous permeable rock that contains an appreciable amount of gas, oil, or water, is called a reservoir rock. However, we must distinguish between permeability and mere porosity: porosity refers only to the *amount* of open space while permeability refers to the ease with which a fluid can move through the openings. The high porosity of volcanic pumice is indicated by the fact that it may float on water although the weight of the stony material of which it is composed is more than two and a half times that of water; its lack of permeability is evident from the fact that large blocks of pumice may float for days before they finally become waterlogged and sink.

Any rock may become a reservoir rock if suitable porosity and permeability are induced in it. Thus an impervious igneous rock may become weathered and porous before burial, or openings may be created in it by fracturing. Such openings are accidental, and it is exceptional to find them carrying oil. Until oil actually moves in, a stratum is only a potential reservoir rock. The closer such a potential reservoir lies to a source bed, the more likely it is to receive oil; it is thought by some geologists that oil may move across hundreds of feet of strata, but a few believe that the movement is very small. The character of the sediments during the time when the oil takes part in this vertical migration is probably important. Since lithification decreases permeability, fluids would naturally cross a much greater thickness of unconsolidated sediments than of lithified beds.

Igneous rocks, metamorphic rocks, and shales make poor reservoir rocks. Oil is found in them at a few places where suitable openings have been induced by fracturing or solution, but they account for only a small fraction of 1 per cent of the world's oil. Sand, sand-

stone, and sandy beds probably account for three-fourths of the known oil, and nearly all the rest comes from porous lime rocks.

Oil traps

In porous rocks such as sand or cavernous limestone, gas, oil and water separate into three layers. If the porous strata are overlain by an impervious cap rock such as shale, the gas rises till arrested by the cap rock and, if the beds are tilted, migrates upward along the contact of the two beds. Where the beds are bent into a dome-like structure, gas is trapped at the crest of the dome, oil concentrates just below the zone containing the gas, and water lies below the oil. Except where surface water has been able to circulate in the rocks, the water associated with oil fields is a strong brine similar to seawater but is more concentrated. Although they are commonly associated, both oil and gas are occasionally found alone, and in a few places oil and gas occur with no water present.

Any barrier to the migration of oil in a reservoir rock is called an oil trap if it either halts the movement or slows it so that petroleum accumulates behind the barrier. Several kinds of oil traps are indicated in Figure 24.

The most important traps are the folds commonly called anticlines or domes, and the "stratigraphic" traps where the barrier to migration is an abrupt change in the character of the strata. A sand bar buried in clay would make an excellent oil trap, but the barrier to migration would be only the abrupt change in permeability where the sand graded into the contemporaneous clay. Stratigraphic traps are much more difficult to discover than structural traps. To this type belong the greatest oil fields in the world, such as the East Texas field, and the Lake Maracaibo field of Venezuela. The future search for oil will probably bring more and more of them to light.

Petroleum is even more sensitive to metamorphism than coal. At comparatively moderate temperatures and pressures, low-grade asphaltic oils are converted into high-grade paraffin oils, and these change to gas if the pressures and temperatures increase appreciably. In regions where coal has been changed into hard coal of a semi-bituminous or anthracite grade, there is almost no possibility of finding oil; in a region where subbituminous coal is present, the interlayered reservoir rocks might contain a moderately good grade of petroleum; where only lignite is found, asphaltic oil would be expected.

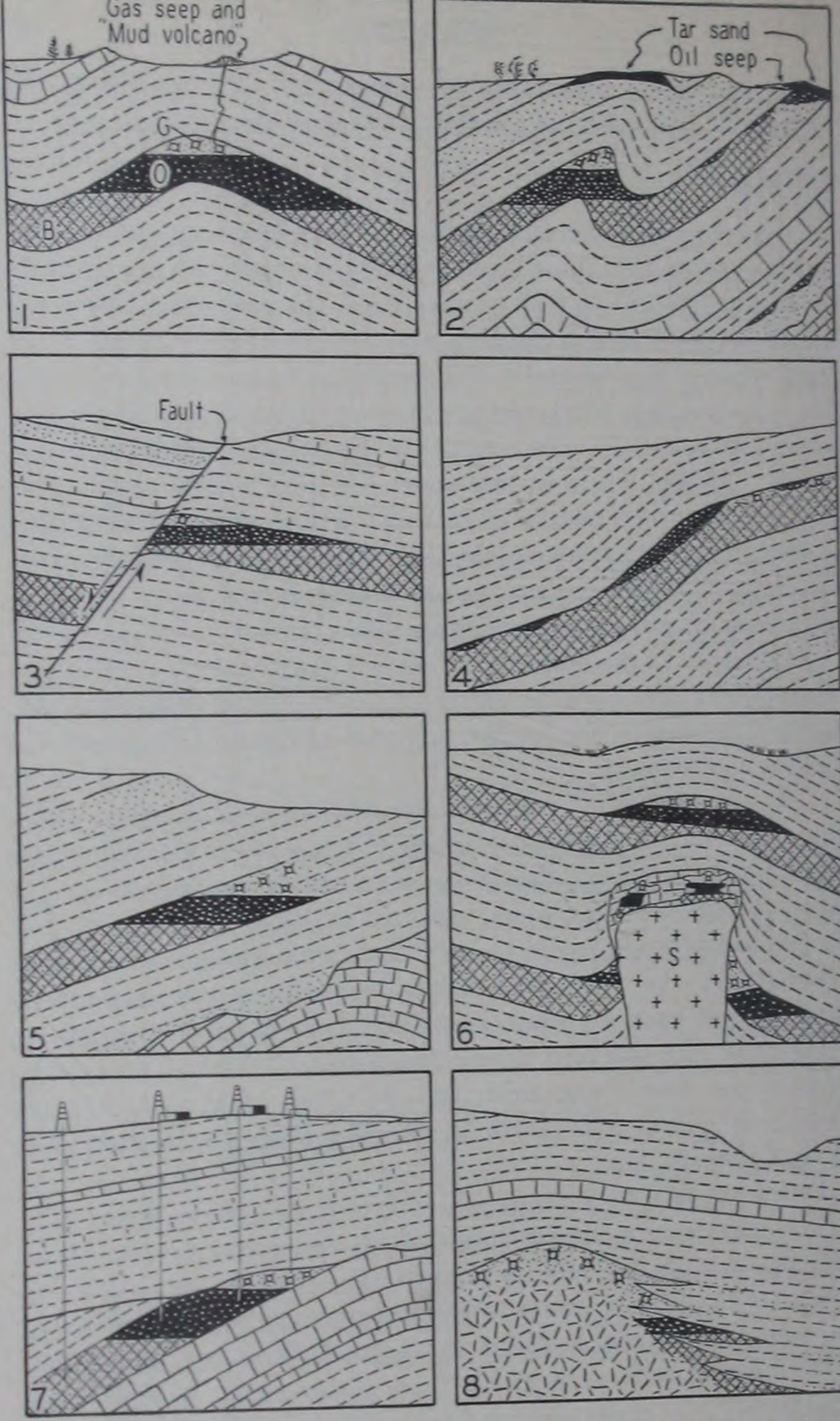


Fig. 24. Common types of oil traps: (1) Symmetrical anticline. G, sand saturated with gas; O, sand saturated with oil; B, sand saturated with brine. (2) Asymmetric anticline. (3) Sand sealed by fault. (4) Monoclinal fold or structural terrace. (5) Lensing sand, e.g. sandstone grading into shale. (6) Salt dome, oil accumulations in upturned sands at side, in cap rock, and in gently flexed overlying sand. (7) Oil accumulating at an angular unconformity. (8) Buried granite hill.

Geologic Distribution

The oldest known rocks that have been regarded as petroleum source beds are of Ordovician age. All the pre-Cambrian terrains of the world are eliminated from consideration by oil geologists. Some oil has been found in all the Paleozoic systems, but most of the production has come from the Ordovician and Carboniferous sediments. In the central and eastern United States, Paleozoic rocks have yielded a large quantity of petroleum; but elsewhere in the world, the beds of this age have produced only a very small amount. The older Mesozoic systems have also been relatively unproductive, but Cretaceous rocks are the source of a large amount of oil. The Lower Cretaceous is oil bearing in Mexico and Texas and the Upper Cretaceous carries oil from Texas to British Columbia. The Cretaceous beds in Argentina, the Chaco country, and along the north coast of South America are not yet adequately explored and may contribute in the future. The Mesozoic beds in the South American Cordilleran region are too strongly folded and metamorphosed to carry oil.

Although Mesozoic beds are widespread in Europe, very little oil has been found as yet. Jurassic beds produce meagerly in Germany, and the Cretaceous carries a little oil in southern Europe; elsewhere in Europe, the Mesozoic beds have been even more disappointing. However, they carry oil in both Persia and Iraq, and there is reason to believe that further exploration in the Cretaceous rocks of the Near East will be successful. Little oil can be expected from rocks of this age elsewhere in Asia. The search for oil in the Cretaceous beds of Egypt has gone on for some time, and several areas are known that seem to be worth testing. The Mesozoic of Northern Africa is not yet productive but may have undiscovered oil traps that will some day contribute to the world's supply of "black gold." Elsewhere in Africa the character of the Mesozoic beds suggests that they are barren. The Upper Triassic beds carry a meager amount of oil in Seram and Timour but none in Australia.

The marine Tertiary is the most prolific oil-producing system of all. For the most part, marine beds of this age are close to the existing seas. In North America oil-bearing Tertiary formations occur in California, Texas, and Louisiana. In South America the marine Tertiary carries much oil in Venezuela and Colombia and an unknown amount in the region east of the Andes near the headwaters of the Amazon River. Most of the oil produced in Europe

comes from mid-Tertiary beds in the Soviet Union near the Caspian Sea and from other Tertiary formations in Rumania near the Black Sea. In Asia, extensive marine Tertiary beds lie just east of the Ural Mountains and may produce oil in the future. This belt extends south into Persia and Afghanistan. Oil has been found in it in Persia. A narrow north-south strip of marine Tertiary in eastern India is oil bearing, and its southeastern continuation in the Dutch East Indies is highly productive. Elsewhere in Asia little oil has been found. Except for small areas of marine Tertiary in northern Africa, both the Dark Continent and Australia seem almost devoid of Cenozoic beds that might carry oil. The distribution of important oil fields is shown in Figures 17–19, 21–23.

Some Major Oil and Gas Fields of the World

East Texas

The East Texas oil field, discovered in 1930, is the largest single field in the world. Its output was rigidly restricted in 1933, but before proration was put into effect it was producing more than a million barrels a day and was creating such an oversupply that the price of oil dropped to five cents a barrel in April 1933. The field is in central eastern Texas about a hundred miles east of Dallas. It is about ten miles wide, forty miles long, and includes about 110,000 acres. The field extends almost due north along the eastern edge of a regional syncline or structural basin where the basal sandstone of the Upper Cretaceous system is overlapped by younger Cretaceous shale and marly limestone. The oil has accumulated in the westward sloping sand where it feathers out between impervious younger beds and a dense Lower Cretaceous limestone which underlies it in the syncline. The conditions are similar to those shown in No. 7, Figure 24. It is a typical stratigraphic trap and is concealed by 3,700 feet of overburden. The yearly production is held to about 140,000,000 barrels and the total production through 1940 was 1,571,000,000 barrels. The oil is high grade and is associated with a moderate amount of gas that was originally under a pressure of about 1,600 pounds per square inch.

The Balakhany oil field

Most of the oil produced by the Soviet Union has come from a small area near Baku on the western side of the Caspian Sea. The

Balakhany field is about seven miles northeast of Baku and is one of the most productive fields in the world. Its total production through 1936 was 1,589,000,000 barrels, and its annual output was about 25,000,000 barrels. It is a sharply folded sinuous anticline that trends north-northwest and contains several minor bulges separated by unproductive saddles. The eastern limb of the anticline dips northeast at 15 to 27 degrees, with the steepest inclination next to the center of the fold. This peculiar type of structure is characteristic of weak beds that have been severely compressed; further evidence of the strong orogenic forces involved is found in the many northeast faults that break the anticline. Some of them have displacements of several hundred feet. The producing beds are Tertiary sands which are interbedded with clay and limestone. The oil measures are about 3,500 feet thick and oil has been found in 34 separate sands, some of which are 200 feet thick. Unlike many fields, the oil in the shallower beds is of higher grade than the oil found at greater depths.

One of the curious features of the district is the great Bog Boga mud volcano which stands more than a hundred feet above the surrounding plain. It was built up of the mud thrown out of a gas seep where natural gas leaked out of the underlying oil trap. In considerable portions of the field, water has risen along many faults and ruined sands that were formerly productive. The modern methods of oil production that were introduced by Soyustneft, the Soviet Oil Trust, promise to avoid this hazard in the future. (3, p. 658; 10)

The Oklahoma City field

Both the geologic and very recent history of the Oklahoma City oil field are interesting. After several dry holes had been drilled and the district given up, geologists of the Indian Territory Illuminating Oil Company, by means of a piece of brilliant geologic reasoning, deduced the probable existence of the oil rock a few hundred feet below the deepest hole. Their company quietly leased thousands of acres of land and then, late in 1928, within a few yards of an abandoned derrick, drilled a well that produced 20,000 barrels per day at a depth of 6,400 feet. However, the structure was so much larger than had been anticipated that the most prolific part of the field lay outside their land and was soon wastefully overdrilled. Billions of cubic feet of gas were blown into the air from wells high on the structure in the hope of reducing the volume of

the gas cap to such a degree that oil would rise to these wells. It is estimated that 760,000,000,000 feet of gas were wasted in the first six years. The rapid drop in gas pressure that resulted prevented millions of barrels of oil from getting to the surface. Twice the governor proclaimed martial law in this area in order to enforce regulations restricting the output of the wells. It was this field, within sight of Oklahoma's capital, and the East Texas field, that forced the lawmakers to prohibit the wasteful practices that formerly ruined so much of our heritage.

The geology of this field explains why it remained so long undiscovered in the heart of a great oil-producing region. Its structure is suggested by Figure 9, No. 3. In early Carboniferous time when this area lay almost awash in a Paleozoic sea, a northwest fault appeared in the country just south of where Oklahoma's capitol was built some 265,000,000 years later. On the west side of the fault, the beds were bulged up in a sharp fold that pushed the surface into a ridge with an abrupt cliff or scarp marking the fault. This hill was gradually cut down by erosion. From its crest, layer after layer was whittled away until the lowest Paleozoic rock systems were exposed. The soft but very porous Ordovician formation, called the Wilcox sand, was stripped away until its outcrop was confined to the truncated limbs of the faultfold. At this stage of erosion, the hill was submerged in an advancing Carboniferous sea and was soon buried beneath clay and limestone. The forces that bent the older beds so sharply were nearly spent, but their last feeble efforts produced a slight uplift in these later sediments above the site of the buried anticline. It was this slight structure that led to the early barren test wells; it was the discovery in another part of the state that a period of folding had occurred just prior to the deposition of the Middle Carboniferous rocks that led the geologists of the Indian Territory Illuminating Oil Company to suspect the presence of the buried anticline. Unfortunately for them, they had no way of knowing that the richly productive Wilcox sand had been eroded from the high part of the structure before the unconformable Middle Carboniferous sediments were deposited. However, the limestones into which they drilled were sufficiently porous to make good reservoir rocks, and if ruinously competitive drilling and wasteful producing methods had not been employed in the field outside their lease, they would have made a very substantial profit.

Extensions of the field have been found to the northwest, and these newer areas are being conservatively managed. The total

production of the field through 1940 was 526,000,000 barrels, and its annual production in that year was 37,800,000 barrels.

Spindletop, Texas

The Spindletop oil field, which represents a geologic type previously unknown, was one of the first to be discovered in Texas. The monotony of the flat, expressionless coastal plains that border the Gulf of Mexico is slightly relieved at many spots by the appearance of low, broad hills that rise from twenty to fifty feet above the lowlands. Some of these mounds have small ponds of bad water perched on their summits; many are surrounded by a belt of salt-water marsh that is well above sea level. The hunters who prowled the coastal plains fifty years ago little realized that the mounds, salt marsh, and perched ponds of bad water were spoor from the biggest game in Texas.

Somewhere in the depths, perhaps twenty thousand feet below the surface, great salt beds were laid down in Mesozoic or late Paleozoic times. Under heavy pressure, salt behaves in a surprisingly fluid way, and these deep salt beds have locally bulged up in great columns in response to regional pressures. The salt is so much lighter than the surrounding rock that it has a strong bouyant force that pushes it upward just as a clot of oil is pushed up through molasses. These masses of salt actually domed up the overlying beds and then breached them, breaking upward through them in the same manner as a mass of intrusive igneous rock, although the salt itself was a sediment. The movement of the salt plugs has been intermittent through the millions of years since they started their upward migration. The horizontality of the beds above some of them show that they have halted for a time far below the surface; others are even now slowly moving upward and bulging the ground up into a low hill. As they approach the surface, the easily soluble salt contaminates the ground water, and thus their presence is reflected by a salt marsh above. A cap of the relatively insoluble material associated with the salt gradually accumulates as a porous cap and sheath around the upper part of the plug, and this makes an ideal reservoir rock. The beds above a deep salt plug are domed up, and if reservoir rocks are present in these overlying sediments, another oil trap may thus form well above the salt. Oil may also accumulate in the beds at the side of the salt plug where they were dragged upward as the salt mass pushed through them. (See Figure 24, No. 6.)

Not all salt domes have oil, but a large number of those close to the Gulf Coast have proved productive. Many have gas under great pressure associated with the petroleum; it is the leakage of this gas that fouls the water in the ponds at the surface.

The presence of sulphurous incrustations in the soil of the broad low mound that rose about fifteen feet above the plains three miles south of Beaumont, and the small ponds of evil-smelling water, suggested to A. F. Lucas the possibility of sulphur at depth. In 1901 he drilled a well in search of this mineral, and it penetrated the porous cap rock of the salt plug at a depth of 1,139 feet. The well tapped not sulphur but gas and oil under terrific and completely unexpected pressure; derrick and tools were literally blown off the surface. When brought under control, the well proved to be one of the largest "gushers" ever to be drilled in the United States; its initial production was 75,000 barrels a day. The field was rapidly drilled and it was soon found that the oil was apparently limited to a circular area covering about 225 acres, but it was many years before the geology of the field was deciphered. There is much free sulphur in the cap rock at Spindletop, and the oil is a heavy, low-grade sulphurous oil. Only a small amount of petroleum was found in the gently arched beds that lie between the cap rock and the surface, but since 1924, when the structure of salt domes began to be better understood, many productive wells have been drilled into the upturned beds at the side of the dome. (See Figure 24, No. 6.) The total production of the Spindletop field in 1940 was 115,797,000 barrels, and its annual production at this time was 600,000 barrels.

The Amarillo field

The Amarillo gas field is more than two hundred miles long and is from five to forty miles wide. It extends northwest from Oklahoma into the Texas panhandle, where it bends northward into Kansas. It is one of the largest and most important fields in the entire world. From it gas has been piped to Denver, Colorado; Dodge City, Kansas; St. Paul, Minnesota; Chicago, Illinois; Detroit, Michigan; Indianapolis, Indiana, and to many cities in Texas and Oklahoma. The gas is withdrawn at the rate of about a billion cubic feet per day, but the field is so vast that this rate can be maintained for many decades.

The gas field was discovered by a geologist in search for oil. Although the presence of gas under a pressure of about 430 pounds per square inch was ascertained in 1918 when the first well was

drilled, it was not until four years later that some interest was aroused in the commercial value of the gas. The real magnitude of the field, which embraces some 2,000,000 acres, was not appreciated till about 1925. It is estimated that the gas reserves (at a pressure of two pounds per square inch) amounted to about 13,707,000,000,000,000 cubic feet in 1935.(2) A small amount of oil is present at many places between gas and brine, but the proportion of gas to oil is very high. It is an interesting coincidence that the water stands almost exactly at sea level throughout most of the district, so that wherever the reservoir rock rises above this level gas is assured.

The Amarillo gas field owes its existence to a chain of mountains that were heaved up in the early part of the Carboniferous period at about the time the structure of the Oklahoma City field developed. After these premonitory rumblings of the Hercynian revolution subsided, the mountains gradually weathered, and the basins to the north and south filled with sediments that overlapped farther and farther toward the crest of the range until, in Middle Carboniferous time, the sea again completely covered this region. The coarse sandy wash that spread out adjacent to the granite hills made an excellent reservoir rock, and the carbonaceous sediments in the basin to the north provided a great blanket of source material. It is believed that the gas has migrated many miles into the trap formed by this buried mountain range, going much farther than most of the oil with which it was originally associated. The structure of the Amarillo field is suggested by No. 8, Figure 24. This petroleum may be that now found in the oil fields to the north, farther down on the flanks of the Andarko basin.

The Maracaibo basin

Perhaps the greatest oil field in the world outside the United States is found on the eastern shore of Lake Maracaibo in northern Venezuela. The Maracaibo basin is a broad topographic and structural trough lying between two northward-trending branches of the Venezuelan Andes. The long, shallow arm of the Caribbean Sea that extends south along the center of the trough is called Lake Maracaibo, and on its steaming shores the major oil companies of the world have built hard-surfaced roads and ultramodern settlements for the men charged with extracting the black wealth that lies beneath both lake and jungle. Oil was taken from shallow pits as early as 1883, but the modern development dates from 1922 when a well drilled by the Shell Company blew in out of control and pro-

duced 900,000 barrels of oil in nine days and then sanded up and stopped flowing. This spectacular performance focused the attention of the oil men of the world upon Venezuela, and, encouraged by the liberal laws and apparent stability of the Venezuelan government, many major companies obtained concessions and rapidly developed producing properties. Special equipment now permits them to drill wells eight miles or more from shore in sixty feet of water to the producing sands 3,000 feet below.

Many closely spaced fields form a nearly continuous producing area along the northern third of the eastern shore line. The southernmost of these fields, the Lagunillas, produces about a third of Venezuela's oil, and its total production in 1941 was almost a billion barrels. The oil occurs chiefly in middle Tertiary beds. Where these beds are locally broken and folded, oil traps have been made at the crest of the folds; the stratigraphic trap is by far the most important type, however. The sediments along the east shore of Lake Maracaibo dip west with a nearly uniform slope and become markedly more sandy in this direction. Some of the lower Tertiary sands (Oligocene) were partly eroded and then overlapped by clayey middle Tertiary sediments (Miocene); oil has accumulated in vast quantities at this unconformity, presenting an occurrence strikingly similar to that of the East Texas field. Some of the reservoir beds were permeable all the way to their outcrop, and much oil has seeped out along their truncated edge. Sun, air, and water have combined to convert much of this leaking oil into a heavy tar which has gradually sealed up the pore spaces in the reservoir bed near the surface. As a result, oil has accumulated again down dip from these tar seals.

Nearly all of the oil is heavy and low grade. It is noted for containing an appreciable amount of the uncommon metal vanadium. The soot from boats that burn this oil is an important auxiliary source of this strategic metal and is carefully collected for shipment to western Colorado where it is treated in the chemical plant of the Vanadium Company of America.(3, p. 597–603; 13)

Production and Consumption

For many years the world has produced a little more than two billion barrels of petroleum annually, and of this huge amount the *United States* produces about 60 per cent. Surprisingly enough, about 90 per cent of this is consumed at home; or to state it in a different way, 6 per cent of the population of the world consumes nearly 55 per cent of all the oil produced. Gasoline is far cheaper

here than in most countries, in spite of taxes that amount to more than 100 per cent of the cost of manufacture. The average retail price in the United States in 1935 was eighteen cents per gallon; in London, England, thirty-five cents per United States gallon; in Rome, eighty-four cents per United States gallon. Production of the leading oil-producing countries is given in Table XLIV in the Appendix.

The *Soviet Union* produces about 10 per cent of the world total and is now normally the second largest producer and consumer. Her output has increased steadily during the last twenty years but her exports have dwindled as her internal market expanded. (See Table VI.)

TABLE VI

PETROLEUM PRODUCTS IN THE SOVIET UNION IN THOUSANDS OF METRIC TONS
(7.18 Bbls. Equals 1 Metric Ton)(8)

	1932	*1934*	*1936*
Crude oil:			
Production	22,319	25,595	29,200
Exports	526	459	167
Consumption	21,793	25,136	29,033
Gasoline:			
Production	2,459	2,310	3,005
Exports	1,972	1,120	419
Consumption	487	1,190	2,585
Lubricants:			
Production	680	1,372	1,500
Exports	232	305	1,247
Fuel Oil:			
Production	8,470	8,519	9,350
Exports	1,870	1,301	825
Consumption	6,600	7,218	8,520
Total Exports	6,600	4,315	2,449

Venezuela produces only a little less oil than the Soviet Union and consumes less than 2 per cent of it. For more than a decade she has been the greatest exporter of petroleum in the world, and most of it has gone to Europe. The war caused her output to drop from 205,783,650 barrels in 1939 to 184,761,241 barrels in 1940. Contrary to expectation, the "war of machines" did not require expanded output; the potential shortage was largely avoided by drastic curtailment of all civilian use of petroleum in the warring countries. The loss of the normal markets in central Europe was far from compensated by the gain in demand from Great Britain the first

year. As the number of tanks, trucks, and planes increased, however, a larger amount of Venezuelan oil was used.

Iran, the fourth largest producer of oil, has large oil reserves, but her output is tied down to the capacity of her pipe lines. Until additional transportation facilities are installed, her production is unlikely to exceed 80,000,000 barrels, and this output corresponds to the normal demands of her markets. She sends most of her oil to Europe, but also supplies much to Africa, Australia, and the Far East.

The *Netherlands East Indies* stands fifth on the list with a yearly production of about 60,000,000 barrels. Most of this is used in the Far East; the Indies themselves, Asia, Australia, and Japan have been the best customers, with only about 15 per cent of the production going to Europe.

Exploration for oil was carried forward by American, British, and Dutch interests for several years prior to the Japanese invasion in 1941. Only a few areas had been tested at that time, but it seems probable that some new fields will be brought in after the war and that the production of the Indies will not decline materially.

Rumania, the fourth country in 1936, dropped to sixth place in 1941 and will probably be seventh in the near future. Her record production of 64,188,000 barrels in 1936 will probably not again be approached. Unless some quite unexpected discoveries are made, the gradual decline which left only 42,000,000 barrels to her credit in 1941 will continue. She is still the most important exporter in Europe and sends her oil to the countries of central and southern Europe.

The production of *Mexico* is nearly the same as that of Rumania, but it is much more probable that new oil fields can be found here than in Rumania. The cost of exploration and lack of the highly trained personnel required have hindered Mexican development since the foreign-controlled properties were expropriated in 1937. A large proportion of Mexico's oil is exported, and most of the export normally goes to Europe; but under unusual conditions. some may find its way to the Far East.

Iraq, like Iran, has its production limited by its pipe-line facilities; its reserves are such that output could be maintained at the usual level of about 32,000,000 barrels for a long time. Disruption of one pipe-line system in 1940 caused a marked drop; installation of a larger pipe line could result in an equally abrupt increase.

The chief consuming countries are the leading industrial nations.

Their position with regard to imports and total consumption before the war is shown in Table VII. (4; 8; 9; 14)

France normally imports about half of her oil from Asia, chiefly Iraq, about one-third from the United States, one-sixth from South America, and only one twenty-fifth from Europe. She formerly drew heavily on the Soviet Union, but imports from the Soviet Union fell off during the thirties and were replaced by increasing trade with Asia.

In 1938 *Germany* obtained more than half its imported oil from Latin America, about one-fourth from the United States, a tenth from the Soviet Union and Rumania, and the rest from Asia. The sharp decline in European supplies during the previous years was offset by gains in imports from the United States.

The United States and Latin America supplied more than half of the oil requirements of *Italy* in 1938, and most of the remainder was obtained from Iraq, Iran, and Rumania. When Albania was acquired by Italy in 1939, a million and a half barrels of oil at most were added to her yearly supply. She remains dependent on imported and synthetic oils.

The *United Kingdom* produces virtually no petroleum. A shale oil industry has long operated in Scotland, and plants have been built to produce synthetic oil from coal. Here, as in Germany, Italy, and Japan, such measures are justified only during the reign of a war-time economy. In 1938 Great Britain imported about half its oil from South America, one-fourth from Asia (chiefly Iran) one-sixth from the United States, and the rest from various sources within the British Empire.

The figures given in Table VII show the consumption of the various countries just prior to the second world war. The consumption per capita of motor fuels at this time is suggestive: United States, 160 gallons; England, 38 gallons; France, 22.3 gallons; and Germany, 10.5 gallons. Most French, British, and American leaders assumed complacently that the Axis would be defeated by an oil shortage if an effective blockade were maintained. Although Germany, Italy, and Japan are all handicapped by meager petroleum supplies, the blitzkrieg technique developed by Germany demanded only a fraction of the oil that was assumed would be required in a modern war. The profligate use of machines and oil during a short sharp campaign was compensated by long periods of quiescence between campaigns when reserves were built up. It is apparent that Germany's war-time consumption during the first two years of

TABLE VII

PRODUCTION AND CONSUMPTION IN BARRELS OF PETROLEUM PRODUCTS OF LEADING INDUSTRIAL COUNTRIES

Country		*Production*	*Imports*	*Exports*	*Consumption*	*Synthetic Oil Capacity*	*Refining Capacity*
France							
Crude	1937	502,000	43,999,000		44,501,000	437,980	50,000,000
	1936	503,000	45,191,000		45,694,000		
Refined	1937		12,138,954	88,761	(55,000,000)**		
	1936		10,021,421	86,105	(50,000,000)**		
Germany							
Crude	1937	3,176,000	5,124,000		(45,000,000)**		
	1936	3,115,000	4,027,000				
Refined	1937		31,902,524	1,733,516	8,300,000	7,000,000	17,343,290
	1936		27,652,929	2,135,134	7,142,000	(30,000,000 in 1941)	
Italy							
Crude	1937	110,000	6,550,000		(16,000,000)**		
	1936	123,000	2,196,000				
Refined	1937		11,730,722		6,661,000	2,500,000	21,050,000
	1936		11,013,832		2,329,000		
Japan							
Crude	1940	6,636,644			(35,000,000)**	(1941)	(1941)
	1936	2,440,000	24,609,000				
Refined	1940		(3,238,000 ex U.S.)			10,000,000	22,000,000
	1936		5,277,240	559,758			

TABLE VII (*cont.*)

PRODUCTION AND CONSUMPTION IN BARRELS OF PETROLEUM PRODUCTS OF LEADING INDUSTRIAL COUNTRIES

Country		*Production*	*Imports*	*Exports*	*Consumption*	*Synthetic Oil Capacity*	*Refining Capacity*
United Kingdom							
Crude	1937	1,060,000*	15,075,056		16,135,050		
	1936	1,023,000*	14,621,250		15,644,250	1,500,000	(1939)
Refined	1937		72,785,200		72,785,200		51,410,750
	1936		68,716,800		68,716,800		
United States							
Crude	1940	1,351,847,000	42,738,000	51,600,000	1,323,400,000		1,722,435,000
	1937	1,279,160,000	27,484,000	67,234,000	1,239,410,000		1,588,115,000
Refined	1940	1,239,700,000	40,178,000	78,989,000	1,188,500,000		
	1937	1,183,440,000	29,673,000	105,600,000	1,107,513,000		
Soviet Union							
Crude	1940	220,600,000	1,195,000	1,199,000	(222,000,000)**		
	1936	199,635,921	1,000,000	10,750,000	197,856,000		375,931,750
Refined	1937		350,000	16,160,000			
	1936	138,322,700			136,684,200		

† (4 ; 8 ; 9 ; 14)
* Approximate production of shale oil.
** Figures in parentheses are estimates.

war were not as great as her normal peace-time demand. A serious oil shortage could develop only if her refineries and synthetic plants were crippled or if she were forced to fight at a blitz tempo for months instead of weeks.

Japan and the United States, because of the distances to their troops and the need for continual marine transportation of supplies as well as the actual combat needs, both required much more oil than in peace time; but in both countries the restriction of civilian use helped to offset the added demands of the war.

The production of petroleum during certain representative years is shown in Table XLIV in the Appendix.

Commercial and Political Control

British, Dutch, and United States interests have long dominated the petroleum industry. The two greatest petroleum organizations in the world, the Royal Dutch Shell Company and the Standard Oil Company of New Jersey, each have assets of nearly $700,000,000, and each controls an oil production greater than that of the Soviet Union. It is almost needless to say that their interests have often clashed and that both have sought and secured oil lands and markets throughout the world. Together they handle more than 25 per cent of the world's petroleum.

Named in the order of their commercial importance, the leading petroleum organizations of the world in 1940 were: Standard Oil of New Jersey, Rockefeller interests, United States; Royal Dutch Shell Company, British 40 per cent and Dutch 60 per cent; Soyustneft, Soviet Union oil trust; Socony Vacuum Oil Company, United States; Anglo-Iranian Oil Company, British government control; Standard of Indiana, United States; Gulf Oil Company, Mellon interests, United States; Texas Corporation, United States; Standard of California, United States.

Some of these companies are more interested in transportation, refining, or marketing than in production, but more than half of the world's oil is produced by them and a still larger proportion is refined and marketed by these nine "majors."

The commercial control of production in the United States is largely in the hands of domestic companies, but the Royal Dutch Shell produces about 50,000,000 barrels here annually.

The state enjoys a complete monopoly in the Soviet Union, and all production is in the hands of Soyustneft.

In Venezuela, the third largest producer, the law limits the hold-

ings of any one company to 300,000 hectars (741,300 acres). Although the Shell interests first developed the oil fields in this country, their share of the production is now less than that of their rival, Standard of New Jersey. These two companies, together with Gulf Oil Corporation, Socony Vacuum Oil Corporation, and Texas Oil Corporation control almost all of the Venezuelan production.

The petroleum of the neighboring republic of Colombia has been developed almost wholly by American companies.

British interests dominate the Far East, but in recent years the Standard of New Jersey, the California-Texas Oil Company, and the Socony Vacuum Oil Corporation have got a very considerable share of the production and markets of this part of the world.

Two-thirds of the oil produced by Iran is in the hands of the Anglo-Iranian Oil Company; only a slightly smaller proportion of the oil of the Netherlands Indies is produced by the Royal Dutch Shell group. After a long and bitter fight for the oil fields of Iraq, an international company, The Iraq Petroleum Company, was formed in which British, Dutch, French, and American interests participated. This organization has developed the Kirkul oil field east of the River Tigris. Only a small part of its concession has been tested, but the 30,000,000 barrels of oil produced yearly by the Kirkul field could easily be increased. Further expansion must wait on additional transportation facilities.

A British company, the B.O.D. Company, Ltd., in which Italian, French, and German capital was invested, had a concession of 40,000 square miles west of the River Tigris, and large oil-bearing structures are known to be present in this tract. In 1937 the Iraq Petroleum Company acquired control of it, however.

Although an American company (Seaboard Oil Company) acquired the right to explore Afghanistan a few years ago and found much to encourage the hope that petroleum could be found, the work was discontinued after testing only a few of the structures found. So much oil had been found in Iran and Iraq that it seemed uneconomic to develop relatively inaccessible Afghanistan.

In addition to the Royal Dutch Shell group, two other powerful combinations have become increasingly interested in exploiting the Netherlands Indies. The far eastern producing and refining facilities of the Standard Oil Company of New Jersey have been combined with the marketing facilities of the Socony-Vacuum Oil Company; in a similar way, the far eastern activities of the Standard Oil Company of California and of the Texas Corporation have been

pooled. These three groups produce and market nearly all the oil of the East Indies and have carried out extensive exploration programs in New Guinea, Misol, Ceram, Borneo, Java, Sumatra and the Philippine Islands. Many new areas were being tested by these groups when the region suffered the Japanese invasion of 1942.

Influence of Petroleum on National Policies

The chief petroleum problem in the United States has been one of oversupply. Some branches of the government have encouraged producers to agree to curtail production, but, at the same time, other branches of the federal authority have brought suit against operators for so doing. In spite of an exportable surplus, a small protective tariff is maintained on oil. No restrictions have ever been imposed on the exploitation of oil fields by foreign interests. The military aspects of the petroleum supply were in part anticipated in the early thirties when the Navy offered partly to subsidize the construction of unusually fast tankers with gun mounts incorporated in their design. Many of these were built and in service before the war.

Great Britain lacks adequate oil; her vast empire is so poor in this indispensable mineral that it could not supply a third of the needs of England alone. The British government has not only encouraged its citizens to invest in oil properties throughout the world, but is itself an active partner in some of the petroleum companies. Where conditions in foreign countries have been inimical to British oil interests, strong diplomatic pressure has been exerted to secure a more favorable situation. Instances of this motivation can be seen in Great Britain's relations with Rumania, Egypt, Iraq, Iran, and other eastern countries. The fear that the flag would follow the English geologist was largely responsible for the Afghanistan concession going to an American company.

The British Isles are dependent on imported oil. Confidence in its naval power is responsible for Britain's drive to acquire foreign sources of oil and for its indifference to synthetic fuel. A few hydrogenation plants were built before 1939 and the oil shale industry of Scotland was maintained. However, less than 2 per cent of her needs were thus supplied. For the rest she depended on tankers and sufficient sea power to give them safe conduct for thousands of miles.

France evinced more interest in the conversion of coal to oil than did England, but she apparently believed it possible to import

most of her needs during a war. Crude oil is much easier to store than is its refined products. For this reason, France increased her crude oil storage facilities and built many oil refineries in the years preceding the second world war. Her total refining capacity was approximately equal to French consumption at the beginning of the war. The intense interest of France in the plight of Syria was not lessened by the juxtaposition of Iraq and Syria.

Germany, like France and England, was dependent on imported oil. Although the cost of making synthetic oil was four times the market price of imported oil, the Third Reich began building hydrogenation plants in numbers soon after Hitler attained power. The improbability of maintaining adequate imports while at war with Great Britain focused Germany's attention on petroleum substitutes. By the time the war started, it is probable that nearly half of her normal requirements of some 45,000,000 barrels was met by synthetic oil and substitute fuels. The necessity of using petroleum products in quantity for the blitzkrieg tactics employed by her army led her enemies to an erroneous conclusion concerning the total consumption of her military machine. Her shortage of oil required periodic breathing spells during which all activity was so restricted that petroleum supplies again accumulated in quantity. It is probable that these forced rest periods did much to assist the hard-pressed British in 1940 and 1941. If the war had been delayed a few years, the capacity of the synthetic oil plants would probably have been so large that no such pauses in the military operations would have been required.

Italy is deficient in both coal and oil. Her answer to these deficiencies was to seek possible sources of petroleum by conquest and to build refineries to treat imported crude oil. The results of the conquest of Ethiopia were a great disappointment to the Italians. No petroleum was found in spite of repeated and somewhat frantic explorations. Albania was already producing about a thousand barrels per day when Italy took over this small country, and even this meager amount was a welcome addition to petrol-poor Italy. A few hydrogenation plants have been built, but for the most part, Italy remains dependent on imported oil and substitutes. Rumania is her chief source of supply.

Japan requires far more oil than she can produce. Her conquests in China were made possible by oil from the United States, but it should be pointed out that adequate supplies would have been forthcoming from the Netherlands Indies and the Near East if the

United States had placed sanctions on oil at any time during the first seven years after Japan's soldiers started marching in 1932. The problem of obtaining sufficient petroleum engaged the best Japanese brains for a long time. The source of the desired oil was apparent, but British and American financial interests had commercial control and the political control was divided between several nations, none of them Japanese. The answer was obvious to the military mind: conquest. As this entailed a conflict with both Britain and the United States, it was essential that adequate supplies should be kept on hand for the period during which these sources of the vital fluid would be cut off. To this end Japan required all commercial petroleum marketers to build large tank farms and to maintain a six-months supply on hand at all times; in addition, the Navy and the Army built up large storage facilities. Refineries also were built by both the Army and Navy, and the number of commercial refineries was increased with utmost speed. During this period of refinery construction, a fleet of the largest and fastest tankers in the world was being built also. When the gasoline without which Japan could not continue her conquest of Asia was finally denied her, she was almost ready. The best oil well machinery in America had been shipped to her, only to be used as patterns for duplication by Japanese machinists in providing the tools to reclaim the wells temporarily ruined by the Dutch.

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Part III

INDUSTRIAL MINERALS: IRON AND THE FERRO-ALLOY METALS

CHAPTER 8

Iron and Steel

Properties and Uses

PURE IRON is a moderately soft malleable grayish-white metal that melts at 1,530 degrees C. (2,786 degrees F.) and boils at 2,450 degrees C. (4,442 degrees F.). It has a specific gravity of 7.55, and its electrical conductivity is about one-seventh that of copper. The variety of uses to which iron and steel is put depends on the great change in the physical properties of iron caused by a small percentage of certain other elements.

Iron is in close contact with coke in the blast furnace, and when drawn off to be cast into "pigs" it has from 3.50 to 4.25 per cent of carbon disseminated through it in the form of graphite flakes and iron carbide. It is the iron carbide that makes pig iron hard and brittle. Pig iron has many other impurities, whose nature and amount depend on the material charged into the blast furnace. Some pig is used as cast iron to make parts that do not require high tensile strength and are not subject to shock, but more than 75 per cent of the pig iron produced is used for making steel.

Steel is an iron alloy that has the property of hardening when quenched from a high temperature. Much steel is iron having less than 1 per cent of carbon. To the special or alloy steels, one or more elements have been added to impart special properties. The most common of these elements are manganese, chromium, nickel, molybdenum, tungsten, vanadium, silicon, and copper. The special properties sought include hardness, stiffness, ductility, resilience, tensile strength, compressive strength, resistance to fatigue, resistance to abrasion, resistance to corrosion, and the ability to hold

a cutting edge at high temperatures. The effect of the various alloy elements is suggested in the following paragraphs.

Low carbon steel goes into wire, tubing, nails, boiler plate, screws, and rivets; medium carbon steel is used for axles, forgings, and machinery steel; high carbon steel makes good chisels, drills, dies, taps, machine tools, and files.

Manganese steel is tough and resists abrasion well; it is especially used for rock-crushing and digging machinery, curved rails, and cross-overs.

Chrome steel is hard, and even at moderately high temperatures it has high tensile strength and resists corrosion. It is used for dies, ball bearings, safes, stainless steel, and chemical reaction pressure chambers.

Nickel gives steel unusual elasticity, ductility, toughness, resistance to corrosion, and when suitably heat treated, hardness. Nickel steels are extensively employed in armor plates and in structural work; they are especially well adapted for use in bridges.

Molybdenum makes steel shock resistant, strong, tough, and hard. Molybdenum steel is widely used in the automotive industry and also in the manufacture of various tools and machinery.

Vanadium imparts qualities to steel similar to those given by molybdenum, but vanadium steels can better withstand fatigue and twisting stress. For this reason it is much used in shafting, axles, and steel springs.

Tungsten makes steel hard and tough, and tungsten steel retains these properties even when heated to a dull red. It is pre-eminent as a tool steel, and its use normally is almost confined to the manufacture of "high-speed" steels; but some is used for making permanent magnets and for other special purposes. In recent years it has been employed to make armor-piercing shells.

Silicon steel is used in the manufacture of certain electrical equipment because of its high resistance and large magnetic permeability.

Copper imparts some of the qualities given to steel by a small addition of nickel; copper steel is finding use in corrosion-resistant tubes and sheet metal.

Wrought iron is a special low-carbon steel that contains a small amount of slag disseminated through it in the form of glassy fibers. The slag is mechanically kneaded into the iron while it is in a hot, pasty condition. Wrought iron is tough, corrosion resistant, and malleable, and makes excellent pipe for pipe lines that are exposed to moist ground.

Substitutes for Iron and Steel

Our modern civilization has no adequate substitute for iron and steel. Under special conditions other materials may be substitutes for a limited amount of steel, and one alloy steel may be substituted for another with similar properties. Concrete ships can be built in an emergency with an appreciable saving of steel; molybdenum steel axles can be substituted for vanadium steel axles, although their life may be shorter. A few years ago, aluminum alloys were employed in fabricating airplanes almost to the exclusion of other metals. The great strength of certain chrome steels allowed such a reduction in the size of parts that their weight was no greater than those made of aluminum alloys. Chrome steel was substituted for aluminum in many places in the airplane, but obviously it is quite possible to return to the use of aluminum instead of steel. A few special pieces of equipment can only be built so as to function when made of certain definite steels. If the steel is not available, no substitute is known that will permit fabrication of the apparatus. However, such special requirements are uncommon and although some special alloy steel may be best adapted for a particular job, usually its place can be taken by a substitute which may be less economic and less durable, or may increase the weight to an undesirable amount before the requisite strength is insured.

Technology

The smelting of iron ore has two objectives: reduction of the ore to metal, and elimination of impurities. The iron in raw ore is combined chemically with oxygen, and the change from ore to metal requires a reducing agent that will unite with oxygen and free the iron. The coke used to heat the charge also supplies carbon that combines with oxygen and thus "reduces" the iron oxide to metallic iron. The most abundant impurities in iron ore are silica and aluminum. If a suitable flux is added, they combine with it to form an easily fusible glassy slag that floats on the molten iron.

Certain deleterious impurities remain in the iron. These must be removed or brought within certain limits before the iron can be used for steel. Oxygen, sulphur, and phosphorus are the evil trio of steel. The presence of any one of them induces flaws and makes steel brittle. Both oxygen and sulphur may be eliminated or rendered harmless by manganese. Phosphorus is removed by bringing the molten metal in contact with a magnesium-rich rock

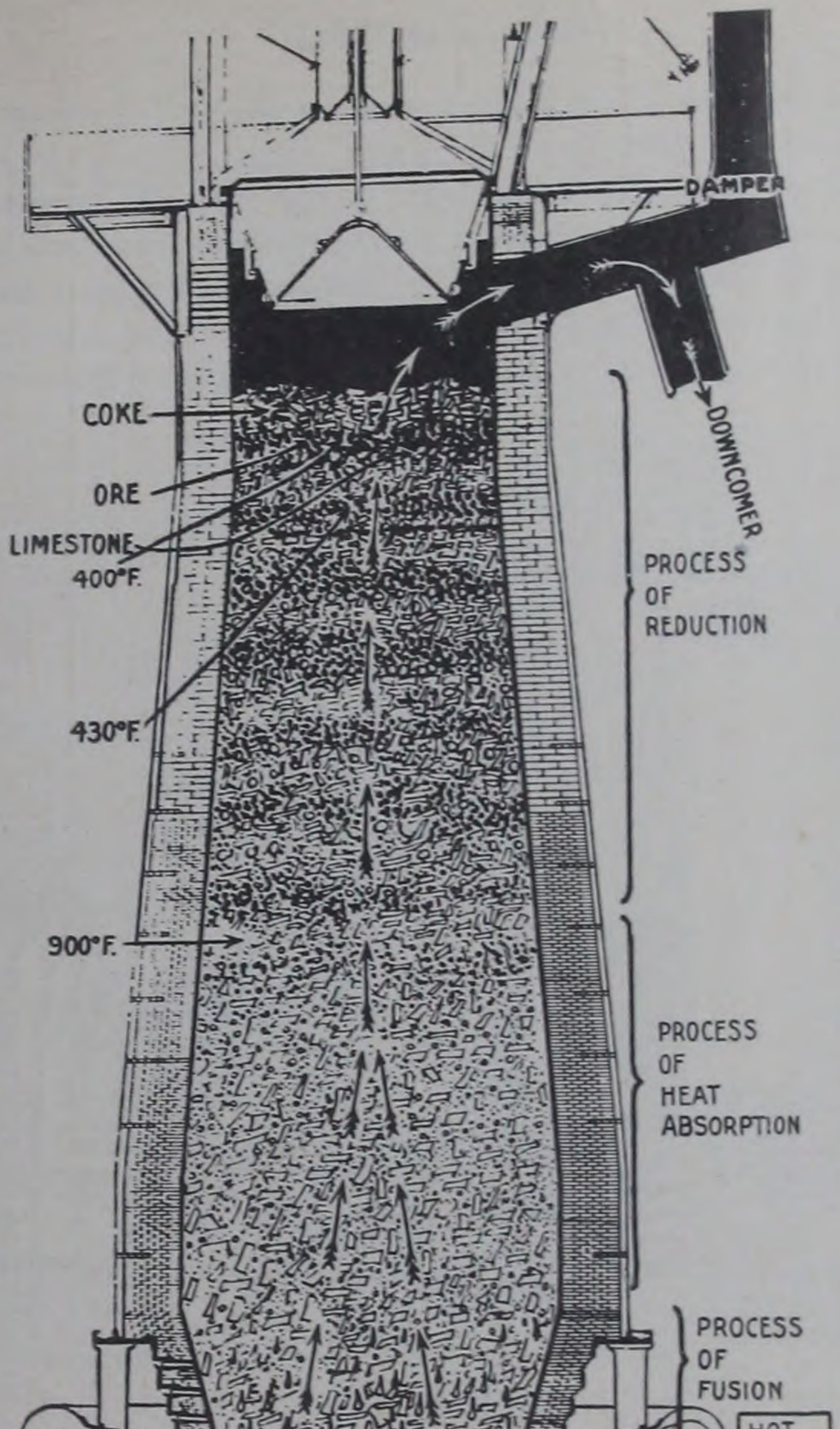
such as dolomite or magnesite. A furnace lined with dolomite brick is said to have a "basic" lining in distinction from an "acid" lining of silica brick.

The high-carbon content of pig iron is lowered by oxidizing it. This can be done by blowing air through the molten iron and is a spectacular process. The carbon monoxide gas that is formed burns furiously until the carbon in the iron is used up and a great shower of sparks shoots up from the white-hot metal during the "blow." (See Figure 27.) The air always oxidizes some of the iron as well as the carbon, and thus a deoxidizer must be added as a preliminary step in all steel making. Manganese is universally employed for this task. About fourteen pounds of manganese are used for every ton of steel manufactured, and the steel industry today is absolutely dependent on manganese for clean, sound metal.

The reduction of iron ore was beyond the skill of early metal workers long after they had learned to smelt ores of gold, silver, copper, lead, and tin. The high temperature required to melt iron was not attained until the blast furnace was developed early in the fourteenth century. For two thousand years prior to this revolutionary innovation, iron had been laboriously kneaded out of a pasty mass of slag, charcoal, and ore at forges.

The Catalan forge, as it was called, had a capacity of 100 to 150 tons of iron per year. The ore, charcoal, and flux were heaped up in a small mound on the forge, heated, and mixed by hand, and from time to time the mass was withdrawn and hammered to break off the slowly forming slag and to agglomerate the reduced iron particles that gradually developed. The metal that resulted from this treatment was similar to the wrought iron of today but had various impurities in it which depended on the character of the iron ore used.

The principle of the blast furnace is simple. A porous mixture of fuel, ore, and flux is fed intermittently into the relatively cool top of a cylindrical stack while the fuel burns near the bottom where a blast of air enters. (See Figure 25.) The intense heat generated in this zone melts both iron and slag, which settle out in the hearth below the blast while the highly heated gases rise through the stack and preheat the mixture above. Slag and molten iron are tapped off periodically through the tap hole. In 1829 Nielson introduced the hot blast, preheating the air to 600 degrees F. before it entered the tuyeres. A third less fuel was required after this innovation was put in use. Cowper invented the regenerator in

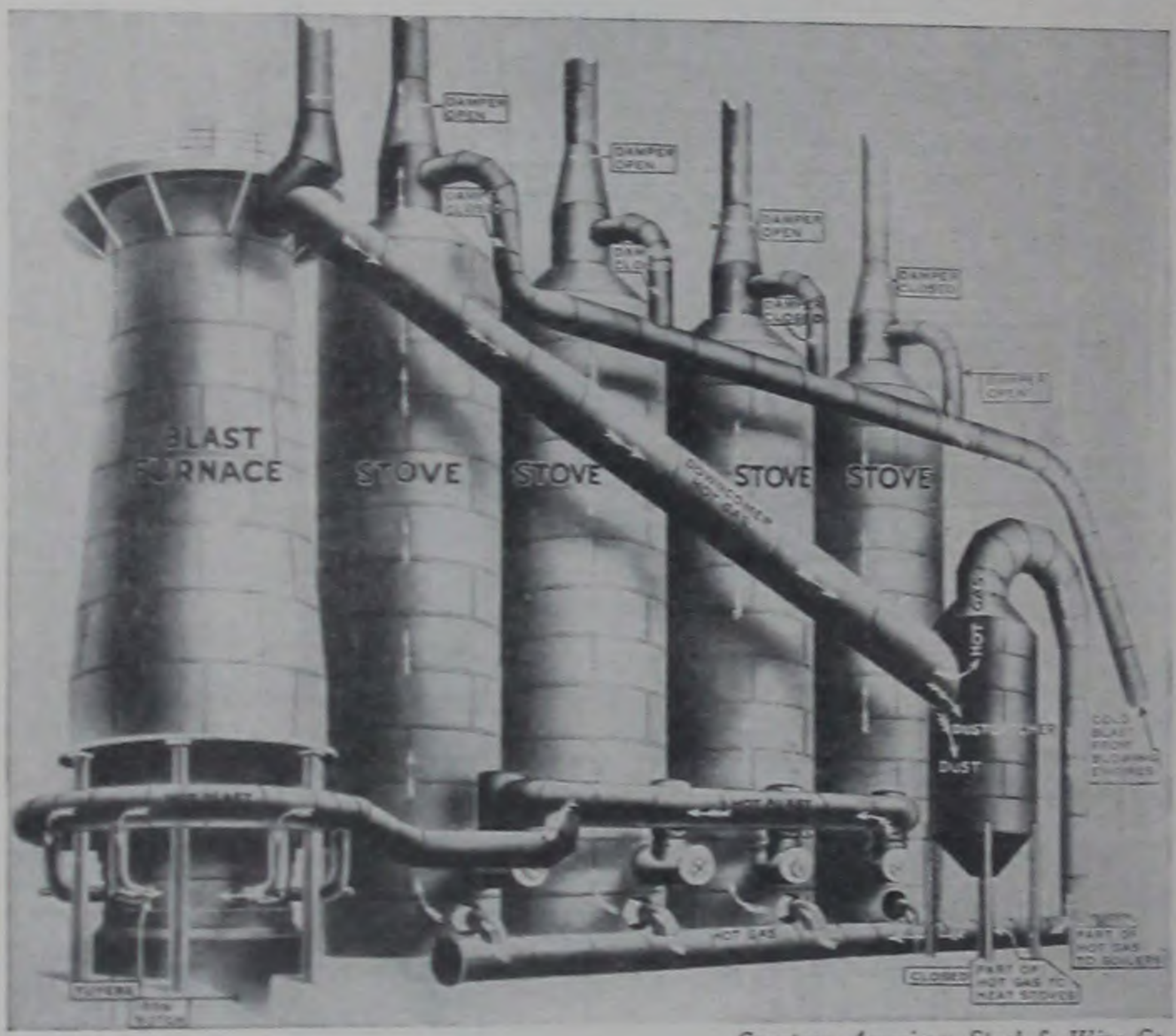


Courtesy American Steel & Wire Co.

Fig. 25. Cross-section of blast furnace.

1857 and made another large saving in fuel. The regenerator stoves of a modern furnace are shown in Figure 26.

As it is essential that the porosity of the charge be maintained, the fuel used must not crush to an impervious powder under the weight of the ore. The early blast furnaces used a good grade of charcoal, but with this fuel the height of the blast furnace was limited to about 25 feet. Ordinary coal breaks down and clogs the



Courtesy American Steel & Wire Co.

Fig. 26. Blast furnace and blast stoves.

furnace, but coke and anthracite coal are strong enough to withstand the weight of a much higher column of ore and fuel. At the present time, coke is almost universally used, and it has made possible the great, "monster stack" blast furnace which is more than a hundred feet high and has a capacity of 1,200 tons of pig iron per day. The ordinary blast furnace produces about 400 tons a day and consumes about 800 tons of iron ore, 400 tons of coke, and 100 tons of limestone.

The use of coke for smelting spread through Great Britain during the first half of the eighteenth century. During the transition from

charcoal to coke, the iron made in British blast furnaces was smelted with the hardest coals available; but the job was done with difficulty. After the ironmasters began using coke, the blast furnace grew steadily in height and capacity while the art of smelting advanced toward a science. Steel making entered its period of great development about 1850, and chemistry and metallurgy moved forward together. Understanding has proved to be the mother of invention.

The three fundamental processes in steel making are: 1) melting the charge; 2) purification of the metal; 3) adjustment of composition. Improvements in the manufacture of steel reflect changes in these three fundamental operations. The improvements in steel itself are largely due to the increasing knowledge of how to change its composition to obtain desirable qualities. The first great innovation in steel making occurred in 1856 when Henry Bessemer described a process for the manufacture of steel without fuel. The essentials of this process are shown in Figure 27. Molten iron is poured into the Bessemer converter to a depth of about eighteen inches, and air is blown through the white-hot melt. The oxygen in the air burns the carbon, manganese, and silicon in the iron and actually heats up the molten iron to a higher temperature. This process effected such a remarkable economy in both fuel and the cost of purification that steel changed from a relatively rare and expensive substance to a cheap industrial commodity.

To make steel in the Bessemer converter, however, the iron had to be very low in phosphorus. Ore to be suitable for making a pig iron of satisfactory grade must have less than 0.10 per cent of phosphorus and is known as Bessemer ore. The Bessemer converter in action is a savage roaring inferno that works quickly but does not allow testing and delicate adjustments in the composition of its contents.

A much closer control became possible when the open-hearth process was invented by William Siemens a few years after the Bessemer process was introduced. A modern open-hearth furnace is shown in Figure 28. A gas flame is led across the surface of a shallow hearth that is filled with iron and on through the "checkers" or "regenerative chambers" before it enters the chimney. These chambers are stacked with loose brick which absorb heat from the hot spent gases. Each open-hearth furnace has two sets of checkers; after one has been heated sufficiently, the exhaust is diverted to the other and the air for combustion is preheated by going

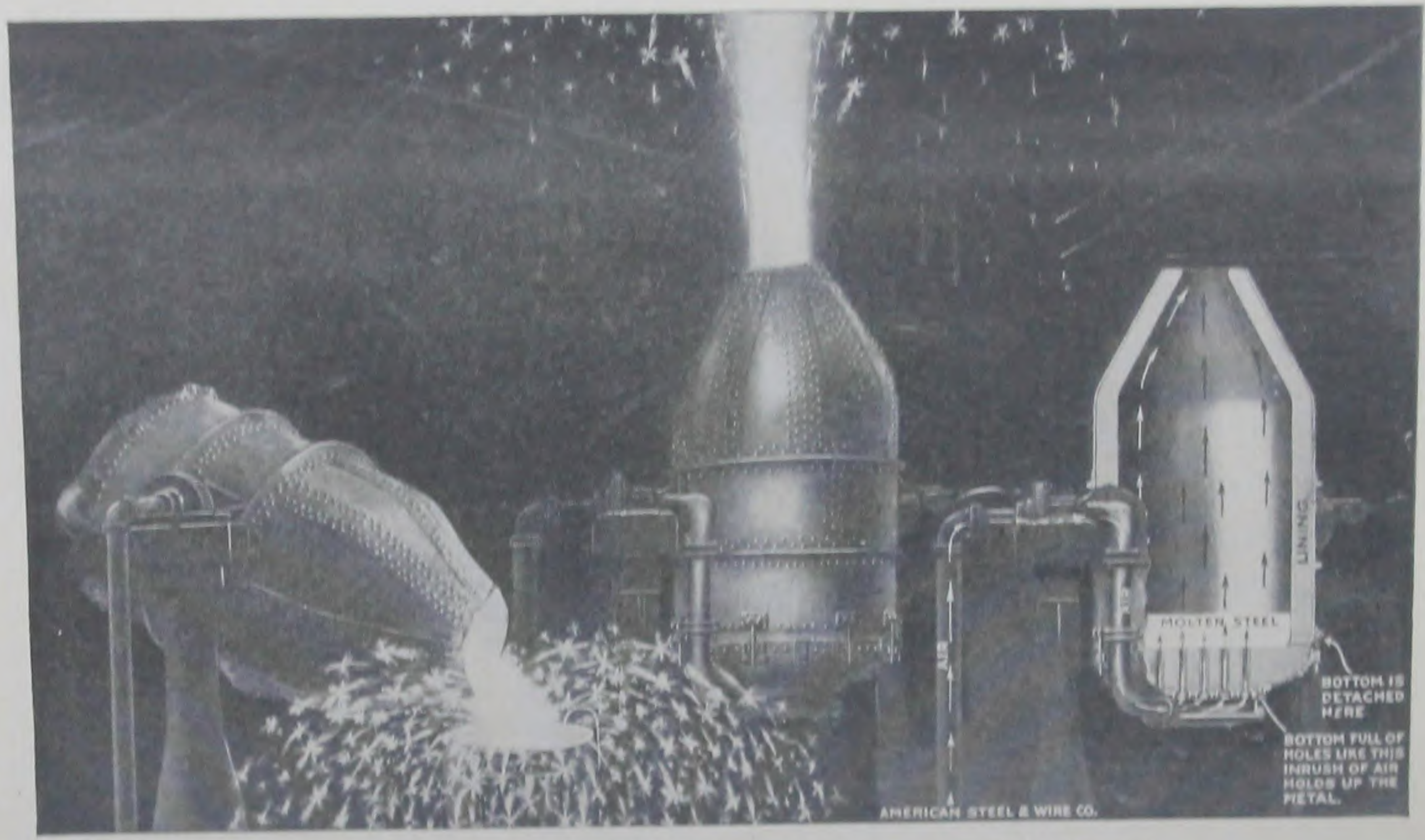

AIR
MOLTEN STEEL
LINING
BOTTOM IS DETACHED HERE
BOTTOM FULL OF HOLES LIKE THIS INRUSH OF AIR HOLDS UP THE METAL.
AMERICAN STEEL & WIRE CO.

Fig. 27. Bessemer converter, showing three stages in the Bessemer process of making steel.

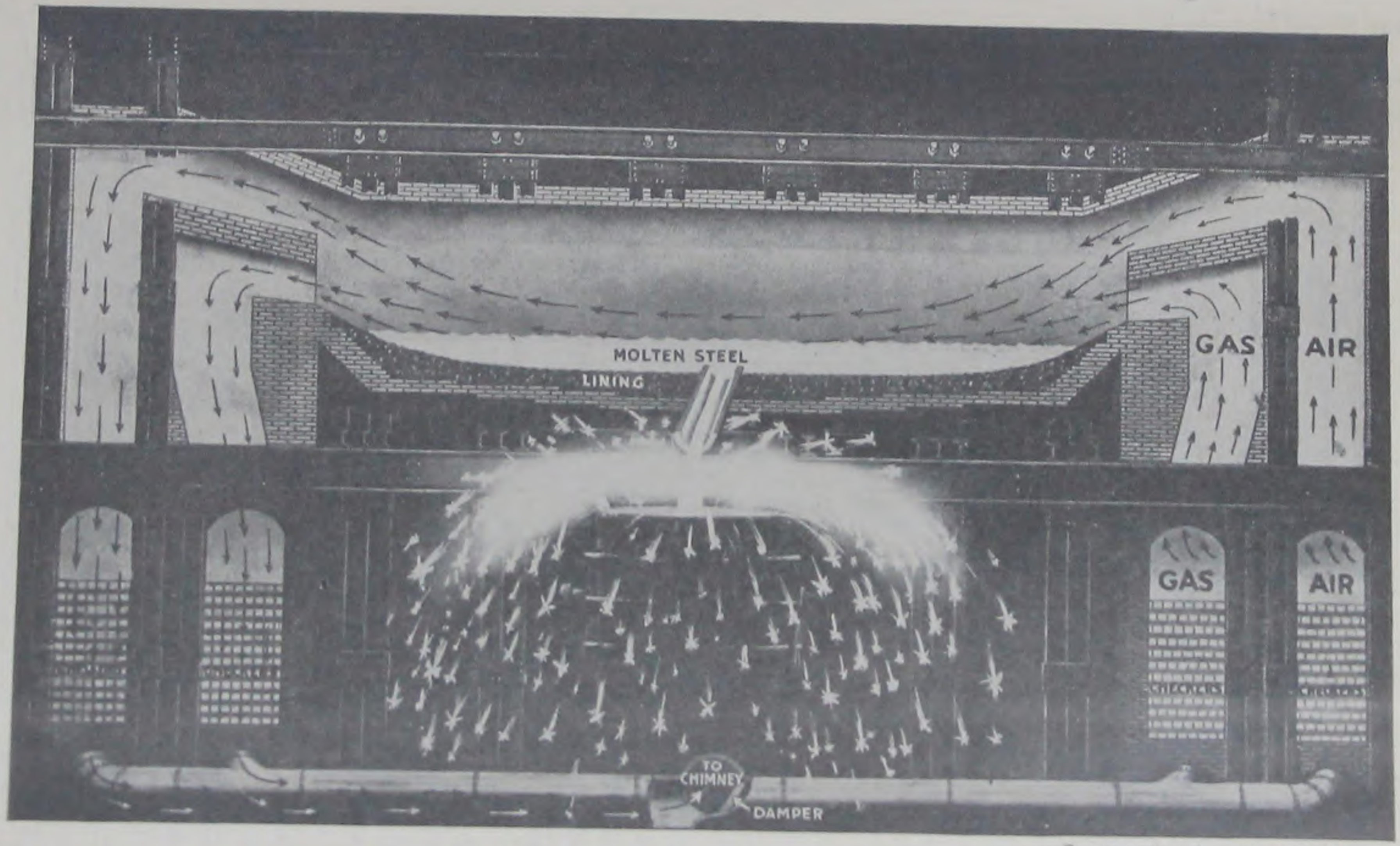


Fig. 28. The open-hearth process of making steel.

Courtesy American Steel & Wire Co.

through the checker that has just been closed to the hot gases. This device saves much fuel and allows steel to be made at a cost not far above that of Bessemer steel. Either solid or molten iron can be fed into the open hearth, and part or all of a charge may be scrap.

About 1875 a young Welsh chemist, S. G. Thomas, and his cousin P. C. Gilchrist, both working in a Welsh iron works, began experiments that had far-reaching social and political effects. By 1880 they had perfected a process for removing phosphorus from ores that contained ten or twenty times the allowable maximum for ordinary steel making. This was ultimately accomplished by the simple expedient of lining the open-hearth furnace or Bessemer converter with blocks of dolomite, a magnesium-calcium carbonate rock closely related to limestone. A few years later it was discovered that the union of the phosphorus with the "basic" lining made a phosphatic material that was an excellent fertilizer. The used lining can be ground up and placed on the market as Thomas meal, and is a valuable by-product of the basic Bessemer or basic open-hearth processes, as they are now called.

Low phosphorus ore is scarce; high phosphorus ore is relatively abundant. Vast reserves of phosphatic ore were known in western Germany and eastern France at the time Bismarck redrew the boundary of those countries a few years before the Thomas process was announced. Only the eastern part of the iron ore beds seemed workable in 1871, and this area was, of course, included in Germany under the Treaty of Frankfurt. Although the iron content is low in this "dirt" or minette, as it was contemptuously called, the presence of flux, coking coal, and cheap skilled labor nearby made it one of the most valuable deposits in the world, once the method of handling the deleterious phosphorus was known. The industrial region of the Ruhr basin in Germany and the iron ore of Alsace-Lorraine were firmly and lastingly tied together as an economic unit by Thomas and Gilchrist. The unfortunate fact that a national boundary cut through this unit was soon a source of increasing friction.

Until 1940 it was customary to take samples of each charge in an open-hearth furnace and to make a chemical analysis of it while the iron was kept molten. After the composition was known accurately, the exact quantities of the proper alloy elements would be added. The time spent in making the analysis usually amounted to six or seven hours. The cost of maintaining the furnace in operation during this time was a considerable item, but even more

expensive was the loss of potential production. In 1940, a group of physicists at the University of Michigan worked out a rapid method of spectroscopic analysis that permits the furnace men to learn the composition of the charge within ten minutes of the time the sample is taken.

In modern practice, the best steels are made in electrical furnaces because of the ease with which the temperature, and hence the reactions that take place, can be controlled. The electric furnace is used only for high-cost special alloy steels, as it is much more expensive to operate than the open hearth.

Economics

The price of iron ore depends on its iron content and its freedom from deleterious impurities. The standard grade for which the base price is fixed changes from year to year and differs at different steel centers. In the Lake Superior districts the standard grade contains about 50 per cent iron, less than 0.10 per cent phosphorus, and less than 0.10 per cent sulphur. Such ore is worth from $4 to $5 a ton. Pig iron sells for $20 to $25 a ton, and the price of steel ranges up to several hundred dollars a ton for special high-cost chromium and tungsten alloy steels.

The grade of ore used in the iron-blast furnace is slowly decreasing, and the amount of coal and flux used shows a corresponding rise. In the United States, most furnaces require an ore containing approximately 50 per cent iron; but in Alabama it is possible to use ore carrying only 35 per cent iron. Much of this low-grade ore contains lime and silica in such proportions that little or no flux is needed. At Birmingham, Alabama, there is a fortunate juxtaposition of coal, iron, flux, cheap labor, and cheap transportation; it is this combination that enables the southern steel industry to compete on even terms with the northern smelting centers.

The coal used in a blast furnace is only part of that required in a smelter. Power is needed for compressors, transportation, and the multitude of machines used in a highly mechanized industry. It is more economical to transport the dense and very durable ore than to move coal. The freight rates on pig iron are far higher than the rates on coal and ore. These economic factors tend to concentrate the smelting centers in areas where coking coal is readily available. For a variety of reasons, however, smelters may be built in other localities. The blast furnaces at the southern end of Lake Michigan are the response to demands of a great industrial area

that has abundant steam coal and cheap transportation costs for both coking coal and iron ore. The iron and steel works at Duluth, Minnesota, on the other hand, although having the benefit of cheap iron ore and transportation by water, would probably never have been built if political pressure had not been applied to the steel industry. The location of the Sparrows Point works of the Bethlehem Steel Company in Maryland was determined by the facilities for cheap transportation of foreign ore and domestic coal in a thoroughly industrialized area.

The raw material for a blast furnace and steel works may include much scrap iron. Under certain conditions, the charge may be largely scrap. Furnaces in Argentina, Japan, and other countries where iron ore is absent or inadequate may customarily run on scrap. About one-third of the world's steel is made from scrap, and in the United States this secondary metal is the source of 30 to 40 per cent of the output. In 1940, approximately 19,500,000 tons of scrap were consumed; this was equivalent to 34 per cent of the steel output and was 42 per cent of the pig iron production. Scrap exercises a stabilizing influence on the price of pig iron and thus, indirectly, on iron ore. When the price of pig iron rises, the value of scrap also increases; and as obsolescent equipment becomes more valuable as junk, the supply of scrap changes accordingly.

Scrap has long been an important source of steel; its use in blast furnaces of the United States has been increasingly important since the first world war. Scrap in the blast furnace lessens the demand for iron ore. In 1939, the United States produced about 6 per cent more pig iron than in 1915; but in spite of using lower-grade ore, the consumption of iron ore was 7 per cent less than in 1915. Such reuse of metal is a conservation measure of far-reaching benefit to those nations that employ it extensively.

The trend of iron and steel technology is toward elimination of wasted energy. To accomplish this elimination, impressive coalitions are effected. A by-product coking plant is built in connection with an iron and steel plant which includes blast furnaces, open-hearth furnaces, Bessemer converters, sheet and tube mills, and foundry. The coke produced at the by-product plant is used in the blast furnace next door, and transportation cost is saved; the gas generated is used for heat in the sheet and tube mill or in the open-hearth furnaces; the molten iron is poured into a traveling crucible which conveys it to the steel furnace or converter immediately, thus saving the fuel that would otherwise be required for

melting the pig. The integration of the various parts of the industry in this manner gives an economical but relatively inflexible complex. To be efficient, it must operate continuously and should run at the capacity for which it was designed.

Geology

Iron is the fourth most abundant element in the earth's crust, and is nature's most common pigment. Most of the red, orange, brown, and green in rock and soil are caused by iron compounds. It occurs in nearly all classes of rocks and mineral deposits, but its ores are concentrated in small and widely scattered areas. By far the most important single class is sedimentary iron ore, but many large deposits belong to the groups known as magmatic segregations and contact metamorphic ores. Iron minerals are very common in veins, but rarely do they occur in such quantities as to make their mining profitable. Of the many iron minerals known, only the oxides, hematite (Fe_2O_3), magnetite (Fe_3O_4), limonite (a mixture of hydrated iron oxides), the carbonate siderite ($FeCO_3$), and the ferrous silicate chamosite are important in ores.

Conditions that favored the formation of sedimentary iron deposits have occurred at many times in the past. These conditions might be limited to restricted areas or might be widespread. In pre-Cambrian time, high-grade sedimentary iron ore deposits of a peculiar stamp formed at about the same time in such widely separated places as the present Minnesota, Wyoming, Labrador, Brazil, and India. So similar is the geology of many of the deposits that when the recently discovered deposits of Labrador were examined by a geologist familiar with the Lake Superior region, he instinctively used the formation names of the Lake Superior mining districts.

In contrast to this mineralogenetic epoch, other periods of iron ore deposition seem relatively unimportant. Some excellent ore was formed in southeastern Newfoundland during the Ordovician period; the extensive deposits of intermediate-grade ore that stretch from New York to Alabama known as the Clinton ores were deposited during a part of the Silurian period; moderately low-grade deposits of similar nature were precipitated in the region stretching southeast from England to southeastern France in the Jurassic period. During the Tertiary period, low-grade, iron-bearing sediments were deposited in many localities and, of greater importance, the iron ores previously formed were enriched by the slow weather-

ing of their outcrops. The gradual solution and removal of soluble material increased the proportion of the resistant iron minerals and thus transformed the upper part of many low-grade deposits into commercial ore.

At a few places in the world, igneous rocks occur so rich in iron that they constitute important ore bodies. Unlike most magmatic segregations, these iron ores are found associated with granites rather than with the dark-colored mafic igneous rocks. The segregations are commonly high in phosphorus; some contain other undesirable elements such as titanium and sulphur, and most of them are not yet regarded as suitable sources of iron ore. The most notable commercial deposits of this class are the high-phosphorus magnetite ores of northern Sweden. Similar but smaller segregations are found in the Ural Mountains, in the Adirondacks of New York, and at Iron Mountain, Missouri. Recently, vanadium-bearing titaniferous iron ores of this group in New York have been investigated as a source of iron, titanium, and vanadium, as similar ores are now successfully treated in Europe.

The volatile constituents of an iron-rich magma tend to escape into the covering rocks once the molten rock stops forcing its way upward. If the roof is limy, the iron is quickly precipitated and an aureole of iron ore surrounds the intrusive close to its contact with the country rock. Such ore bodies are "contact ores," more properly called contact metamorphic ores. A large number of ore deposits of this class are scattered over the world. Many of them are moderately large and of excellent grade. They contain far less phosphorus than the magmatic segregations. Like the segregations, they are related to granite rather than to dark-colored rocks such as gabbro. The ores of Elba, chief source of Roman and Italian iron ore, are contact metamorphic bodies, and much of the ore of Japan, China, and Chile belongs in this class.

In many places veins crop out that are rich in iron. In most of the veins the iron is combined with sulphur except where it has been oxidized by exposure to the weather and aerated ground water. The upper part of such a vein becomes enriched in iron oxides and is quite different from the unweathered ore below. This shallow iron caprock is called gossan. In a few places, a sufficiently large deposit of gossan exists to make commercial bodies of iron ore. The copper-bearing gossans of Rio Tinto, Spain, have long been used. The deposits of Bilbao, Spain, are somewhat similar; but below the gossan the deposits consist of iron carbonate with almost no sul-

phides and can be used for ore also. The vein deposits and their gossans are generally quite low in phosphorus. Because of their purity, the gossans of Spanish carbonate ores have been prized by British ironmasters for many years.

Distribution of Iron Ore

Small deposits of iron ore are abundant and widely scattered over the face of the earth. The competition of a few great deposits makes the majority of these small deposits sink into commercial insignificance. In 1940 more than three-fourths of the world's iron ore came from five districts: the Lake Superior district (Minnesota and Michigan) supplied 62,000,000 tons; the Lorraine area, 31,000,000 tons; the Krivoi Rog deposits of the southwestern Soviet Union, 18,000,000 tons; the Kiruna district of northern Sweden, 12,000,000 tons; and the Birmingham district of Alabama, 7,000,000 tons. These five districts accounted for a total of 130,000,000 tons out of the world's 206,000,000 tons. The present output of the other deposits is no measure of their potential productivity, however. One of the greatest deposits of high-grade ore in the world lies in eastern Brazil in the province of Minas Geraes, but only 200,000 tons were mined there in 1940. The extensive deposits at Belle Isle, Newfoundland, produce about 1,500,000 tons a year. Several large deposits of good iron ore are present in Mindanao in the Philippine Islands, but as late as 1941 most of them had produced nothing. However, the production of the Philippine Islands rose from 601,190 tons in 1937 to 1,191,641 tons in 1940 and the output can be increased easily to many times this figure. In contrast, the deposits of Bilbao, Spain, maintained an output of about 3,000,000 tons yearly in the face of dwindling reserves and will probably become of little consequence in the near future. Districts of continuing but not of first importance in the world's supply of iron ore will include: Magnitagorsk and the Ural Mountains deposits of the Soviet Union, north Cuba, Chile, India, north China, and the districts of England. The distribution of these deposits and others is shown in Figures 30, 31, and 32.

Geology of Major Districts

Lake Superior region

Lake Superior lies near the center of a structural trough. The formations on the Minnesota side slope southeast under the lake,

and those on the Michigan and Wisconsin side dip north or northwest. Most of the central part of the basin is occupied by intrusive gabbro and extrusive traprock, but on either side pre-Cambrian sediments are present. These sediments are folded locally into minor basins or troughs. The character of the sedimentary rocks and the succession of the different lithologic types are so similar

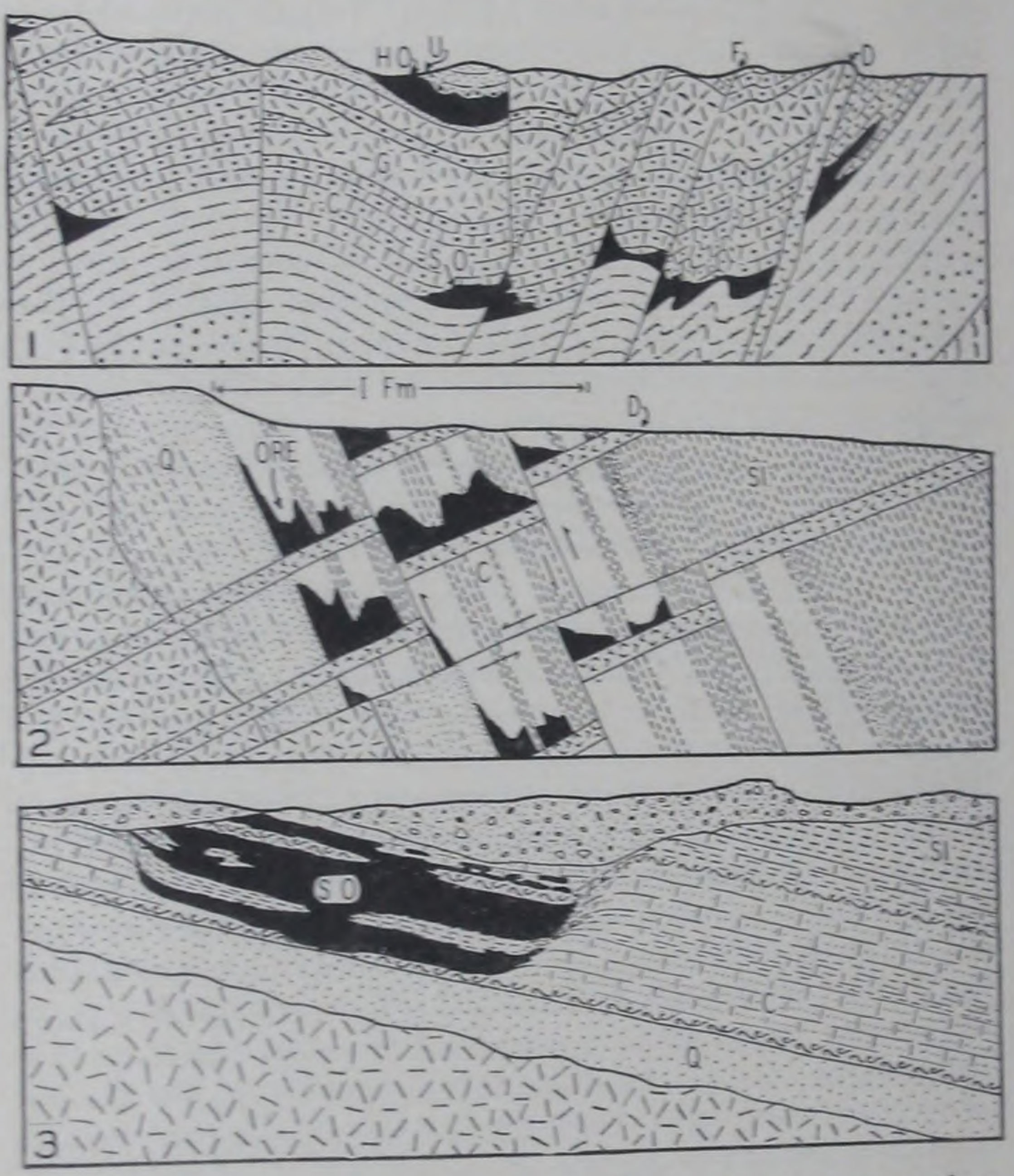


Fig. 29. Diagrammatic sections in Lake Superior iron districts showing occurrence of ore.

(1) Marquette range, Michigan. HO, hard crystalline ore; SO, soft ore; F, fault; D, dike; G, gabbro sill; C, siliceous iron carbonate rock of iron formation from which the iron ore is formed by oxidation of the carbonate and leaching of the silica. The solutions that did this work were guided by structural troughs in the formation, created by folding, faulting, or intrusion.

(2) Gogebic range, northwestern Michigan—northern Wisconsin. SI, slate hanging wall; Q, quartzite footwall of I Fm, iron formation; D, dike.

(3) Mesabi iron range, northern Minnesota.

that the formations in Minnesota can be correlated with those in Wisconsin and Michigan.

Belts of banded hematite and jasper are found at several horizons in the pre-Cambrian, but the most extensive deposits are of middle pre-Cambrian age. Where they are unenriched, the iron ore beds contain 25 to 35 per cent iron; but they are too low grade to be worked in a region so remote from coal and industrial centers. In many large areas the rocks have been intruded by dikes of igneous rock and fractured in such a manner as to promote the active circulation of water through the iron formation. The valueless constituents of the iron formation have been leached along the channels of circulation, leaving a residue of high-grade iron ore. Diagrams illustrating the localization of the ore along such channels are shown in Figure 29. The Lake Superior district normally produces annually from 30,000,000 to 60,000,000 tons of ore which contains approximately 50 per cent iron. The reserves are estimated at 2,500,000,000 tons.

Birmingham, Alabama

The Birmingham district is near the southern end of the Appalachian Mountains. The steel works are only nineteen miles from Port Birmingham on the easily navigable Black Warrior-Tom Bigbee river system. Extremely cheap transportation is thus available to the seaport of Mobile and is an important factor in the economic operation of this great southern center of the steel industry.

Formations representing all the Paleozoic systems are present in the region, but ore beds are found only in a relatively thin Silurian formation. Near Birmingham the Silurian beds have been thrust northwest at a low angle over Carboniferous rocks along a great fault. This geologic accident was a piece of good luck for the United States Steel Corporation, because it brought the beds of iron ore into close proximity to coal beds that otherwise might have lain many miles to the west. Four beds contain mineable iron ore, but nearly all the production is made from the Big Seam, a bed of limy hematite that ranges from 10 to 20 feet in thickness. It crops out on the surface near Birmingham for a distance of about 15 miles, and slopes off to the southeast for an unknown distance. However, one mine in this district has followed the bed underground down the slope for a distance of 15,000 feet. The ore contains about 36 per cent iron, 15 per cent silica, 15 per cent lime, and 0.35 per cent phosphorus and is nearly self-fluxing. What little additional flux is needed is furnished

by the Dolonah dolomite quarries, a few miles from the blast furnaces.

The iron and steel industry of Birmingham is controlled by the Tennessee Coal, Iron, and Railway Company, a subsidiary of the United States Steel Corporation. This company operates blast furnaces, a large by-product coke plant, and steel works. The steel plant includes open-hearth furnaces, Bessemer converters, rolling mills, blooming mills, pipe mills, wire mills, foundries, tin-plate mills, and other departments.

The Wabana or Belle Isle district

The Wabana iron ore beds of Ordovician age just reach the surface at a small island off the southeastern coast of Newfoundland. The ore that crops out in Belle Isle slopes northwestward under Conception Bay, and inclines have been driven out under the sea for a distance of about two miles. The ore beds are lacking on the mainland ten miles away. Bedded hematite occurs in seams from eight to twenty-two feet thick. It is high in phosphorus, but as it carries more than 52 per cent iron, it is in demand for steel plants where the Thomas process is used. The proximity of the ore to a good harbor allows unusually cheap transportation from Belle Isle to its destination. After being pulled to the surface up the incline, only a two-mile haul on an aerial tramway to the southern side of the island is required before it is loaded on ocean-going ships. Of late years, most of the ore has been shipped to Sidney, Nova Scotia, and to Germany. After war was declared in 1939, England received the shipments previously destined for Germany.

According to Hayes, there are reserves of 2,500,000,000 tons of iron ore at Belle Isle.(5)

Cuba

Extensive but little-worked iron deposits occur near the eastern end of the island of Cuba. The Mayari Moa deposits in the north are residual iron ores formed through the weathering of mafic igneous rocks. A small amount of chromium and nickel is present, and the ore is low in phosphorus. However, the ore does not contain more than 40 per cent iron and is not as much in demand as are the ores of the Daiquiri district to the south near Santiago. The iron ore bodies border igneous rocks and were formed by the contact metamorphism of sediments. The ore contains hematite with some magnetite, and although it has a relatively high percentage of sul-

phur, it carries little phosphorus. Reserves in the Daiquiri district are far less extensive than those of the residual ores to the north, but this district furnishes most of the ore exported by Cuba. The total reserves of Cuba are estimated at approximately 3,000,000,000 tons.

Minas Geraes

Probably the largest deposit of high-grade iron ore in the world is in the province of Minas Geraes, Brazil. Tremendous masses of ore that contains 70 per cent iron are exposed at the surface. The thick beds of rich hematite lie in a formation of pre-Cambrian sandstone and crop out over an extensive territory. The iron ore is approximately three hundred miles from the coast and will not be mined in any quantity until improved transportation facilities are installed. Both docks and a railroad were badly needed in 1942 when the United States Export-Import Bank loaned Brazil $14,000,000 for development of the deposits. No satisfactory coal supply is available near by for smelting the ore, and for many years almost the entire output, which is expected to range from 500,000 to 1,500,000 tons annually, will move to the United States or northeast to Europe. The reserves of iron ore in this district are estimated at 7,500,000,000 tons.

The Lorraine district

The sedimentary rocks in the western part of Germany dip westward toward France and form the eastern rim of a large, shallow structural basin known as the Paris basin. The beds of low-grade sedimentary iron ore are interbedded with Jurassic shale, limestone, and sandstone. Most of the many ferruginous beds present are too thin to work, but a few of the mineable beds are as much as twenty feet thick. Like the iron ore of Birmingham, Alabama, they contain sufficient lime to make a considerable quantity of the ore self-fluxing. The district is crossed by many faults of slight throw. The ore beds have been residually enriched by the leaching of valueless material at their outcrop. Along many of the faults circulation was especially active, and better-grade ore continued farther from the surface than in the unbroken ground between them. Until after the development of the Thomas process, only the best grade of enriched ore was used.

As noted previously, the vast reserves of primary high-phosphorus ore were of little interest at the time of the Franco-Prussian war.

All the richer shallow ore was included in that part of the Lorraine which Germany annexed. The iron ore east of the boundary was known to be 1,000 to 1,325 feet below the surface, and mining at such a depth was regarded as impracticable because of the character of the deposits. When the high-phosphorus ores became usable, the French went after them with the most modern equipment available and by operating larger units were able to produce ore more cheaply than it could be produced in the German mines across the border. The continued mining of the German deposits had gradually reduced the initial advantage they enjoyed, and by 1910 the cost of mining in France averaged less than in Germany. From this time on, the French mines moved rapidly toward first place in European iron ore production. After France took back the Lorraine at the end of the first world war, her iron ore production exceeded that of all other European countries. It is well to remember, however, that the actual content of iron in the French ore is only half that of Swedish ore and only a little more than half that of Lake Superior ore.

The Jurassic iron formation, which contains the minette ores of the Lorraine, continues northward into Luxembourg and southeastern Belgium. The reserves of these two countries are small compared with that of the Lorraine, however; Kohlmann estimated that over 5,000,000,000 tons of ore are present.(12, p. 63)

The Kiruna district

The great iron ore deposits of Kiruna, one of the most important in Europe, lie in northern Sweden a hundred miles within the Arctic Circle. The ore is more resistant than the adjacent rock and crops out in a ridge which extends north-northeast and rises some 750 feet above the near-by Lake Luossa Jaidi. It is a magnetite body 475 feet wide and about one and three-quarter miles long, and extends to a depth of at least a thousand feet. The ore proved by drilling amounts to more than a billion tons, contains about 60 per cent iron, and is high in phosphorus. The magnetite is a dikelike mass that dips east at about 70 degrees and is believed to be a magmatic segregation intruded between syenite porphyry and quartz porphyry, two rocks closely related to granite. Before the war, about two-thirds of the ore mined went to Germany and about one-third to Great Britain. The ore shipped in recent years has averaged a little more than 60 per cent iron and approximately 2 per cent phosphorus.

The Yorkshire iron district

Most of the iron ore produced in England now comes from the Cleveland Hills in Yorkshire. The ore is similar to that of the Lorraine and, like it, is of Jurassic age. The low-grade unaltered ferruginous beds consist of silica, chamosite and siderite; only at the surface are high-grade iron oxide minerals found. The best seam is a flat-lying bed 66 feet thick, which carries from 28 to 33 per cent iron and is high in phosphorus. Much of the ore extracted had been enriched by weathering. The reserve is estimated at approximately a billion tons.

Krivoi Rog

The Soviet Union possesses one of the best iron districts of Europe in the south Ukraine at Krivoi Rog. The ore deposits resemble those of the Lake Superior region and, like them, are found in metamorphic rocks of pre-Cambrian age. The iron formation is not everywhere of commercial grade, but locally, where it has been fractured, rich deposits of iron ore have been concentrated. Svitalski believes that hot water flowed through the fractured formation, leached out the silica, and left a residual concentration of high-grade iron ore behind.(14) The reserves in this region are not accurately known but it is safe to say there are several billion tons of excellent ore.

Mount Magnitnaya

The steel center of Magnitogorsk is in the southern Ural Mountains. It draws its iron ore from Mount Magnitnaya near by. The ore replaced limestone at the edge of a granite intrusive and is one of the largest contact metamorphic ore bodies known. Its reserve is estimated at approximately 300,000,000 tons. Although coal must be hauled a long way, and the location of blast furnaces, steel mills, and by-product coke plants at the iron mines would seem uneconomic, the strategic value of a steel plant located so far from the border may justify the choice of this site for an industrial center.

Northern India

About a hundred miles west of Calcutta the metamorphosed pre-Cambrian sediments that crop out contain interbedded iron formations which dip northwest at a low angle and are easily mined. The ore contains approximately 62 per cent iron and is relatively

low in phosphorus. The mines are only forty-five miles south of Kali Mati, the center of the Indian iron industry, where the Tata iron works are located. The presence of adequate supplies of coking coal near Kali Mati makes this district capable of producing the lowest-cost pig iron in the Orient, and is transforming northern India into an industrial region coveted by other countries.

China

The iron ores of China are relatively small bodies of contact metamorphic origin and are found in limestone bordering granite or syenite, a rock closely related to granite. A number of ore bodies of this kind lie south of the Yangtze River near Hankow. There are large reserves of low-grade magnetite-bearing metamorphic rock in Manchuria. Under normal conditions, such ore bodies could not be mined economically; but because of the military importance of its iron and steel industry, the Japanese government sudsidized the mining of Manchurian ore for many years. Within the Japanese islands themselves are many small contact metamorphic bodies of iron ore; from these bodies Japan ekes out her meager production of domestic ore.

Consumption and Production

During the 15-year period, 1926 to 1940, the world produced annually an average of 145,000,000 tons of iron ore, 80,000,000 tons of pig iron, and 101,000,000 tons of steel. The minimum production was in 1932 and amounted to about half of these figures. The production in 1940 was approximately one-third more than the average. The production of iron ore, pig iron, and steel during the representative years 1929, 1932, 1936, 1937, and 1940 is given in tables XXXII, XXXIV, and XXXV in the Appendix.

The leading coal-producing nations of the world are the leading producers and consumers of pig iron and steel. The iron and steel industries of the United States and the Soviet Union are essentially self-sufficient; those of Great Britain, Germany, France, Japan, Belgium, and Italy lean heavily on imports of ore, coal, or iron.

The United States

The production of iron ore, pig iron, and steel in the United States ranges between 25 per cent and 40 per cent of the world's peacetime total. The smaller figure represents her proportion of the

minimum world production and the higher figure the percentage of the maximum output. The accented variation in the domestic industry is evident. The United States both imports and exports a small amount of iron ore and pig. Normally the imports of iron ore exceed exports and amount to about 1.5 per cent of her total production. The reverse is true of pig iron, and normally the balance in favor of exports over imports amounts to about 1 per cent of total production.

Although the domestic market absorbs most of the steel produced, an appreciable amount is exported. Previous to the depression, the exports amounted to about 4.5 per cent of production; but from 1934 to 1939, the exports mounted to 10 per cent, and during 1940 the exports as well as the profit made by the steel companies doubled. It is interesting to note that in 1939, when Japan was building up a stockpile against anticipated emergencies, she took more than 2,000,000 tons of scrap from the United States, but that in 1940 she apparently felt so nearly prepared for war that the United States sold her only a third of the 3,000,000 tons exported. In the industrial countries of the world, a general rearmament program got under way in earnest about 1936 and was immediately reflected by increased steel production. It was also reflected by a sharp climb in exports of steel products from the United States. During this period, Japan was our best customer, and Great Britain and Italy almost tied for second place, with Germany not far behind. In 1940, when the German and Italian markets were cut off, Great Britain jumped to first place, claiming more than 45 per cent of all our export steel. Canada was second with 11 per cent, and Japan dropped to third; but Japan and Great Britain each took 34 per cent of the scrap exported in 1940.

In the United States, the iron and steel industry is run by Big Business. The United States Steel Company has 40 per cent of the steel-producing capacity of the country, and with eight other companies controls 82 per cent of our capacity. In 1938, according to the Iron and Steel Institute, the nine leading producers had a capacity of 59,078,200 tons of steel ingots and 42,037,200 tons of pig iron. These figures accounted for 82.5 per cent and 82.9 per cent of the country's capacity respectively. These companies can be credited also with a fair share of the 60 per cent increase in capacity that the United States made in the next few years. The capacity in 1938 is listed in the accompanying table.

TABLE VIII

CAPACITY IN TONS OF NINE LARGEST STEEL COMPANIES*

Name	*Steel Ingots*	*Pig Iron*
United States Steel Corporation	25,790,000	20,470,000
Bethlehem Steel Corporation	10,042,000	6,588,000
Republic Steel Corporation	6,500,000	3,800,000
Jones and Laughlin Steel Corporation	3,671,200	3,162,000
National Steel Corporation	3,400,000	2,100,700
Youngstown Sheet and Tube Corporation	3,120,000	2,850,000
Inland Steel Company	2,760,000	1,327,000
American Rolling Mill Company	2,045,000	684,000
Wheeling Steel Corporation	1,760,000	1,046,000
Total	59,078,200	42,037,700
United States Total Capacity (1938)	71,594,000	50,698,400

* (8, vol. 47, p. 324)

Since 1900, the steel industry in the United States has become progressively less centralized. At the turn of the century, Pennsylvania possessed unchallenged leadership, producing 56 per cent of the steel. At this time Ohio produced 19 per cent, the Illinois-Indiana steel centers 12 per cent, New York a little less than 4 per cent, and the other states less than 9 per cent. By 1940 the standings of these areas had changed so that Pennsylvania produced 29 per cent of the total, Ohio 19 per cent, New York 6 per cent, Illinois and Indiana 22 per cent, and other states about 23 per cent.

North-Central Europe

The shifting boundaries in Europe make it difficult to discuss the iron and steel production of the various countries as such. However, the geographic location of the iron and steel centers is relatively fixed even though their nationality may change from time to time. Certain natural economic units can be discussed as such.

The iron ore of the Lorraine is the natural complement of the coal in Belgium and the Ruhr basin of Germany. To utilize a transportation system efficiently, a pay load must be borne in both directions. Ruhr coke moves to the blast furnaces and steel plants of Lorraine in about the quantity that iron ore produced in the Lorraine is smelted there, and slightly more than half is exported to other countries. Normally about 6,000,000 tons go to the Ruhr and 10,000,000 tons to Belgium. For many years the steel produced in Germany, France, Luxembourg, and the Saar was under the control of the European Steel Cartel.

Luxembourg-Saar region. Luxembourg lies between the coal

fields of the Saar and Belgium, and exchanges her iron ore for coal from both areas. About half the iron ore produced is exported and the remainder is smelted in Luxembourg. Belgium only produces approximately 3 per cent of the iron ore consumed in her blast furnaces and steel mills. Two-thirds of her imports normally come from France, most of the rest is received from Luxembourg, and a small amount of high-grade ore is imported from Sweden.

Swedish iron and Silesian coal. The Upper Silesian coal fields lie at the headwaters of the Vistula and Oder rivers. The coal makes excellent metallurgical coke, but the thin limonite ores of Silesia are low grade and production is small. Most of the iron ore smelted in Silesia is imported from Sweden. However, a substantial amount of the charge to the blast furnaces consists of scrap iron.

Germany. The Ruhr district is less than a hundred miles from the North Sea. Its steam and coking coal is abundant and of excellent quality and is cheaply mined. The three leading iron ore districts of Germany, namely those of the Piene-Salzgitter, the Siegerland, and the Lahn-Dill, lie to the east, southeast, and south of the Ruhr and are all within 150 miles of one another. The low quality and comparatively small production of the German iron ores create a demand for imports of high-grade ore. The proximity of the Ruhr district to the coast makes possible the cheap importation of Swedish iron ore to this district, which has long been the market for the greater part of the iron ore shipped from Sweden.

It is difficult to estimate what Germany's "normal" consumption of iron ore and "normal" production of iron and steel would be if no armament program had sapped her energy and artifically stimulated her heavy industries. However, during the late nineteen-twenties, when Marshal Foch declared her to be completely disarmed, Germany imported about 15,000,000 tons of iron ore and produced about 6,000,000 tons of ore, 12,000,000 tons of pig iron, and 14,000,000 tons of steel annually. Her production of ore, iron, and steel dropped to about one-third in 1932 just before the rearmament program was started. The virtual conscription of labor during the ensuing years and the drive for self-sufficiency in vital war materials during the period spent in building up a vast new armament resulted in a tremendous increase in production of the materials essential to an industrial economy. By 1939 her iron ore production had risen to approximately 12,000,000 tons, and her steel production had reached the record figure of about 24,500,000

tons. This includes the output of plants in what formerly had been Austria and Czechoslovakia; if their production was excluded, it would not reduce the total tonnage by more than a few million tons.

Prior to 1938, Germany's balance of exports over imports of pig iron and steel was commonly 1 to 2 per cent of her total production of these materials. Most of the pig iron was converted into steel, and the steel in turn was converted into fabricated goods for use internally or for exports as manufactured products.

Great Britain

In eastern England, each of four districts still produced in 1942 more than 1 per cent of the world's total iron ore: the Northampton district, the Leicester district, the Lincoln district and the North Cleveland district. The proximity of these districts to the excellent coal of Yorkshire and southern Wales, and the nearness of the Cumberland iron deposits to Northumberland, combined to make this island the industrial center of the nineteenth century. The peak production of 18,327,563 tons was reached in 1882. The iron ore remaining is of mediocre quality and is supplemented by imported ore of much higher grade. England normally imports ore from many localities. The three chief sources before the second world war were Sweden, Spain, and Algeria, each of which supplied approximately 1,500,000 tons of ore. Tunisia, Norway, France, Sierra Leone, and Newfoundland each supplied several hundred thousand tons. Only 25 per cent of the iron produced in Great Britain required low-phosphorus ore such as was obtained in Spain.

In the late nineteen-twenties, Great Britain produced 12,000,000 tons of ore annually and imported 5,000,000 tons. From this ore, 7,000,000 tons of pig iron were smelted. This iron, together with scrap, was converted into 9,000,000 tons of steel. Nearly half the steel was exported either in the form of fabricated goods or as steel ingots and bars. Most of these exports went to the colonial empire of Great Britain. Nearly 3,000,000 tons of iron, steel, and manufactured goods were imported, and so the United Kingdom's balance of exports over imports was only about 16 per cent of her total production. The figures for imports of iron ore and for production of iron ore, pig iron, and steel in the late thirties were almost the same as those for the late twenties; both imports and exports of steel and manufactures fell off until the balance of exports over imports approximated only 5 per cent of Great Britain's production.

After war was declared on Germany in 1939, it became necessary to change a policy that had been established for many years. The danger of submarine attacks on shipping made it desirable to import only the materials that could be consumed within the country. This forced Great Britain's colonial empire to turn still more to other sources for its fabricated goods, and also led to an entirely new policy of encouraging self-sufficiency in the colonies and dominions so far as was possible. Steel plants were built in Africa, Canada, Australia, and India, and manufacturing industries were soon built up to care for war needs. It is unlikely that Britain's colonials will permit these infant industries to die when the war needs are no longer present. It thus seems probable that England's export trade will suffer a blow from which it will be difficult to recover.

The Soviet Union

Although Russia had a substantial output of iron ore and pig iron prior to the first world war, the revolution so completely demoralized the industry that it was 1930 before she equaled the production of 1913. In 1913 Russia mined 9,210,000 tons of iron ore and smelted 4,216,000 tons of pig iron. In 1921 the figures for iron ore and pig iron sank to 140,000 tons and 116,000 tons respectively, the lowest output since 1828. The figures for Soviet iron first reached a million tons in 1925, but from that time until 1940, in spite of many serious setbacks, production of ore, iron, and steel climbed rapidly and steadily. This increase was due in large part to the employment in the late twenties of foreign technical help to plan and supervise the construction of the essential units for an enlarged iron and steel industry. The United States and Germany furnished most of the technicians as well as most of the equipment for revising the industry. By 1936, the last year for which accurate figures are available, the Soviet Union had increased its production of iron ore to 27,918,000 tons, of pig iron to 14,395,000 tons, and of steel to 15,230,000 tons. The yearly output from 1936 to 1940 probably rose at a rate not to exceed a quarter of a million tons per year. The amount of ore and iron imported into the Soviet Union is unknown but is probably small. The grade of the Soviet ore is sufficiently high to permit smelting all of the pig iron from domestic ore. Armament and the continually expanding internal market apparently absorbed nearly all the iron and steel produced by the Soviet Union, and exports during the two decades following the revolution were negligible.

A large part of the Soviet Union's iron ore comes from the Dnepropetrovsk district in the southern Ukraine. This region normally furnishes about 60 per cent of the iron ore, and 25 per cent comes from the Ural Mountains. Most of the pig iron and steel also comes from the southern area; approximately two-thirds of it is produced in the Ukraine, the Crimea, and the Azov-Black Sea region. Second in importance is the eastern area centering around Sverdlovsk and Chelyabinsk. (See Figure 31.) The vast resources of iron ore and the continuous construction of new steel plants in these areas during the late thirties suggests that the capacity of the Soviet Union would continue to increase under normal conditions. The large and expanding internal market assures a consumption that could easily keep pace with the rising output of iron and steel for years to come.

France

Most of the production ascribed to France is from the Lorraine district and has been considered under the heading *Germany*. In 1937, out of the total of 35,500,000 tons of iron ore, all but 2,500,000 could be credited to the Lorraine. Although the production of pig iron and steel is centered in the Lorraine, a substantial amount is also produced in northern France. The blast furnaces of Normandy and Lorraine together produce from 6,000,000 to 7,000,000 tons of pig, and their steel plants convert almost all of it into steel. Approximately half the iron ore and from one-half to one-third of the steel is exported.

Sweden

Sweden mines from 12,000,000 to 15,000,000 tons of iron ore yearly, about 75 per cent of it in the northern part of Sweden near Kiruna and about 25 per cent in the central part near Grangesberg. Both the central and northern ores average more than 60 per cent iron. About 10 per cent of the ore is smelted in southern Sweden and the remainder is exported, chiefly to central Europe.

Italy

Italy has a moderate supply of iron ore in the island of Elba but mines only enough to supply about a quarter of her requirements. In 1938 Italy was able to get from domestic ore and scrap only one-third of the iron for the 2,322,000 tons of steel produced. Coal resources are so limited that she is unable to produce more than

20 per cent of her needs. The lack of coal constitutes a serious handicap that has been overcome to some degree by the development of hydroelectric power, but the use of electricity is justified only for a relatively high-priced product such as alloy steel. Italy's steel industry depends to a large extent on imported iron and steel scrap because of the relatively high cost of pig iron, whether produced domestically or imported from abroad. Steel imports, other than scrap, were discouraged by high import duties prior to the second world war. About half of the Italian steel went into armament.

Spain

The production of iron ore in Spain has been fluctuating but declining for the past forty years. Prior to the first world war, the production stood at slightly less than 10,000,000 tons but dropped to about half that figure by the late twenties. During the following decade it commonly ranged between 1,500,000 and 2,500,000 tons. About two-thirds of the ore was exported and the remainder was used to support a small domestic iron and steel industry. By far the major portion of her export trade has been with Great Britain, but an appreciable amount also moved to German furnaces. Spanish steel production, which amounts to approximately 750,000 tons a year, draws on imported scrap and domestic pig iron in nearly equal amounts.

Japan

Japan is deficient in iron ore. Her domestic output is only a little more than 750,000 tons per year. This is supplemented by imports from China, the Malay States, and the Philippine Islands. Nearly all the iron ore produced in the Malay States has been under Japanese control and was exported to Japan. The exports increased from about 1,500,000 tons in 1935 to approximately 2,000,000 tons in 1939. The conquest of northern China opened up the valuable resources of the Chahar province in 1937. It is estimated that Chahar contains reserves of at least 90,000,000 tons of iron ore, about 40 per cent of the iron reserves of China.

The Japanese iron and steel industry has been artifically sustained for many years by the military and has been employed almost exclusively for producing steels for the manufacture of armament and ship building, the two major heavy industries of Japan. The production of pig iron in Japan rose from 1,250,000 tons in the late

nineteen-twenties to 3,000,000 tons a decade later. Her imports of iron ore in 1935 and 1936 were 3,400,000 and 3,780,000 tons respectively, and during these two years she imported a little less than a million tons of pig iron chiefly from British India and Manchuria. The preparations for war with the United Nations was reflected by a steadily rising production of steel. The Japanese output increased from 3,047,000 tons in 1933 to 6,339,000 tons in 1940.

It was possible for Japan to increase her production of steel much more rapidly than her production of pig iron and iron ore because of the tremendous quantities of scrap iron and steel that she was able to import, largely from the United States. Approximately 60 to 70 per cent of the charge used for making steel in Japan consists of scrap, and Japan's production of steel is approximately double her production of pig iron. From 1934 to 1939 it is estimated that she acquired 16,765,000 tons of scrap. During this same period she produced 17,600,000 tons of pig and imported about 5,000,000 tons. In the 6-year period 1934 to 1939, 8,663,000 tons of scrap and about 750,000 tons of pig iron and ferro-alloys were shipped from the United States to Japan. The imports of scrap iron from other sources amounted to 2,564,000 tons. The remainder of the 16,765,000 tons of scrap used came from large quantities obtained in Korea, Manchukuo, and the occupied parts of China, supplemented by domestic sources. In all, 31,600,000 tons of steel came from this pig and scrap during this 6-year period and virtually all was consumed in armament and preparation for war.

Commercial and Political Control

The commercial and political control of iron ore deposits is identical in most of the countries where iron, steel, and iron ore are all produced within the boundaries of a single nation. United States capital controls relatively few foreign ore deposits, but the important supplementary sources of iron ore for the eastern seaboard that are found in Cuba and Chile are controlled by American interests, and some American capital is invested in Brazilian iron deposits. The iron ore produced in Great Britain and her colonies is under British control. British commercial interests also control most of the iron ore produced in Spain for export to Great Britain. French capital controlled most of the ore produced in Tunisia, about 20 per cent of that produced in Algeria, and nearly all of the French output, although capital from Belgium and Luxembourg

also was invested in the Lorraine. Before 1940, German capital controlled all the iron ore produced in Germany and Austria; but aside from a small proportion of the insignificant production of Rumania, it controlled no other sources of ore, so far as is known. The Swedish government is financially interested in the iron industry and for many years has been exercising an increasing control over operating companies. Foreigners cannot operate mines or become directors in mining companies, except with the consent of the government. German capital has been more heavily invested in fabrication plants than in mines in Sweden during recent years. In Belgium, domestic capital controls all the production of pig iron and steel. The iron ore produced in Luxembourg was entirely controlled by Luxembourg financial interests, and more than 80 per cent of the iron and steel was also under domestic commercial control. Most of that produced in the Saar was also controlled by Luxembourg, but one-third of the Saar iron and steel was in the hands of German and French capital. The iron ore of Chosen (Korea), Manchukuo (Manchuria), China, Japan, the Philippine Islands, and Malaya was under Japanese control in 1942.

In summary it may be said that during the nineteen-thirties more than 90 per cent of the iron came from deposits that were owned domestically. This percentage included the iron ore produced in the United States, the Soviet Union, Great Britain, Germany, India, Newfoundland, Spanish Morocco, Tunisia, Australia, Italy, and Sweden. It should be noted, however, that in the case of Sweden some of the ore was leased to German and Austrian operators. Swedish operators also controlled most of the ore produced in Norway and Algeria.

Influence on National Policy

Steel is the heart of the modern industrial system. Cheap steel is essential to commercial competition, and the political policies of our leading nations reflect this knowledge. The inability of German capital to acquire control of foreign sources of iron ore to supply her furnaces was probably one of the guiding forces behind her acquisition of Czechoslovakia, Poland, Belgium, and the Lorraine. In these countries and Germany was concentrated between 30 and 35 per cent of the world's iron and steel production and sufficient ore to provide the raw material for a third of the world's pig iron when supplemented by that of the Swedish deposits.

Her shortage of iron ore has led Japan to make an intense effort

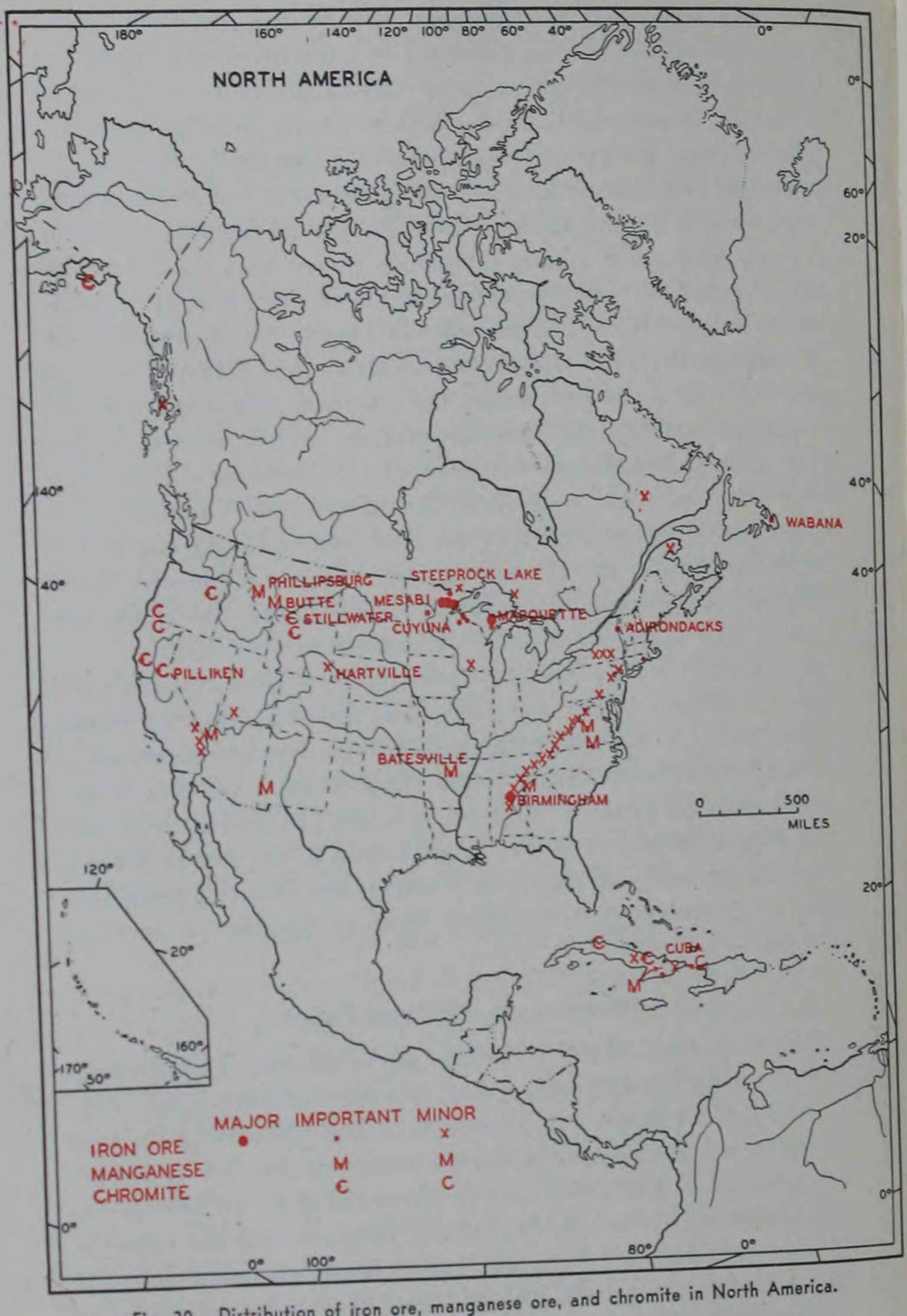


Fig. 30. Distribution of iron ore, manganese ore, and chromite in North America.

Fig. 31. Distribution of iron ore, manganese ore, and chromite in Europe.

to acquire foreign sources of supply. The Japanese are the sole exploiters of the Malayan ore deposits and were active in exploring British Malaya, Australia, and the Philippine Islands in search of possible ore deposits in the years preceding the second world war. Japan's conquest of Manchuria and north China was motivated in large part by her desire to acquire the mineral deposits that these regions were known to possess, and the chief prizes sought in addition to markets were the deposits of iron and coal.

In conclusion it may be pointed out that the countries or regions situated most favorably for production of cheap iron and steel are the United States, Great Britain supplemented by Spain and Scandinavia, Belgium-Ruhr basin-Lorraine area, Silesia and Sweden, the Ukraine, the southern Ural Mountains, and northern India. Regardless of the success or failure of political struggles for their control, these regions, because of temporary geologic conditions that existed more than a hundred million years ago, are destined to continue as centers of industrial supplies for mechanized civilization.

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CHAPTER 9

Manganese

Uses

MANGANESE is the Achilles heel of the steel industry. Sound steel cannot be produced without the use of a small amount of manganese to remove the oxide formed by melting the iron preparatory to purifying it and making it into steel. Manganese also functions as a desulphurizer, an essential role if any sulphur is present in the melt. An average of fourteen pounds of manganese is used for every ton of steel manufactured. However, in addition to its function as a deoxidizer and desulphurizer, the manganese imparts many desirable qualities to steel. Some steels contain far more manganese than others and are known as manganese steel.

If steel contains from 11 to 14 per cent of manganese, it can be made almost nonmagnetic by quenching it; in this condition it is a much poorer conductor of heat and electricity than is ordinary steel and finds extensive use in the electrical industry. Manganese steel is unusually tough and resistant to abrasion. The life of manganese steel rails is five to six times that of ordinary carbon steel rails. It is the best steel for machines whose parts are subject to heavy abrasion and wear, such as are used in mining, milling, digging, rock crushing, road working, and dredging. Manganese steel is also used in certain types of tool steel. However, the amount of manganese used in manganese steel is a small percentage of that used as a deoxidizer of all steel.

About 5 per cent of the manganese produced is used in the chemical industry, about 95 per cent in the metallurgical industry. The chief use of manganese in the nonmetallurgical industries is in the manufacture of dry batteries, paints and varnishes, disinfectants, and coloring material; it is also used as a decolorizer of glass.

An alloy containing 80 parts of copper, 18 parts of manganese and 1.5 to 2 per cent of nickel is known as manganin; because of its extremely high electrical resistance, this alloy is widely used in

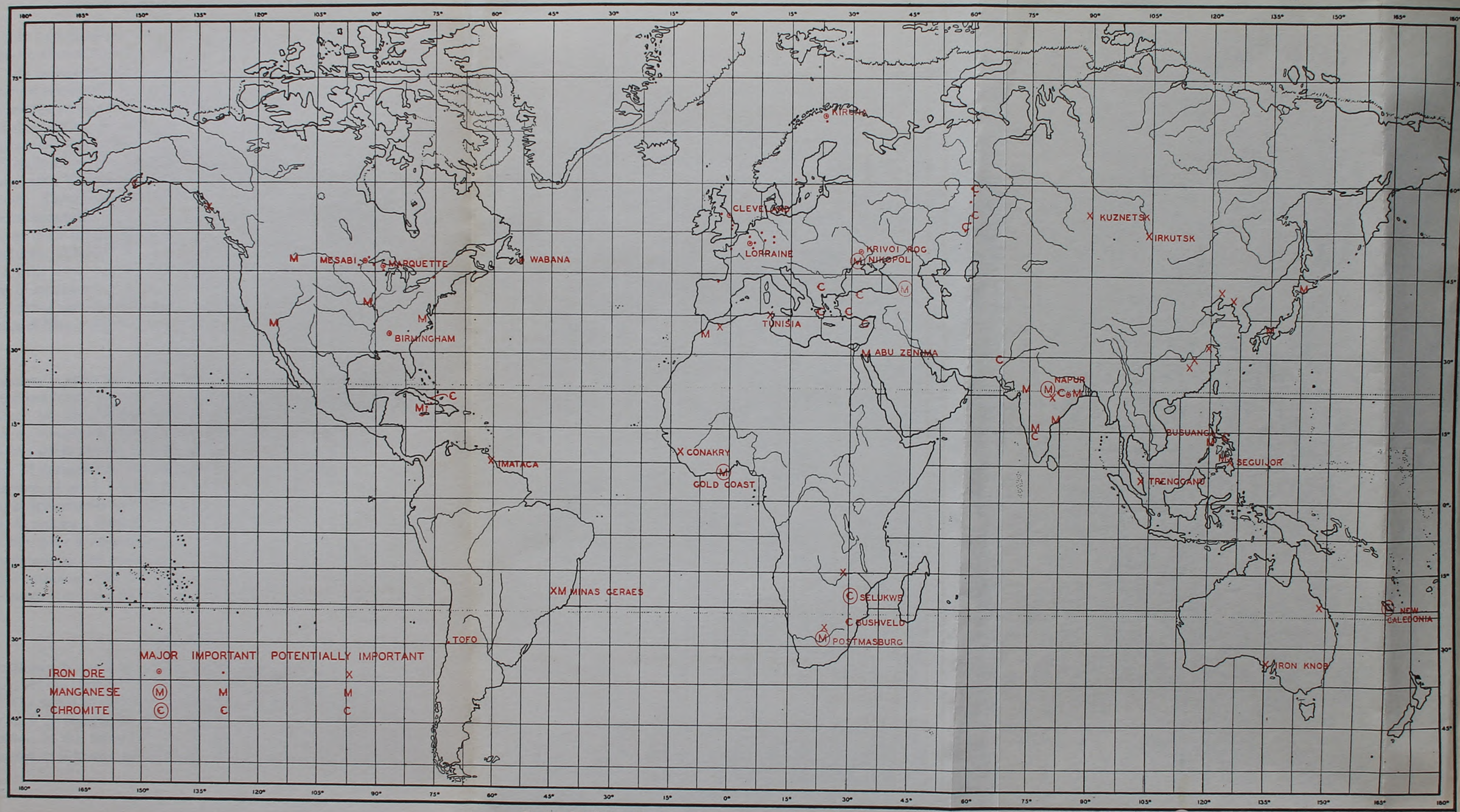

Fig. 32. Distribution of iron ore, manganese ore, and chromite throughout the world.

heating coils and electrical furnaces. Manganese is also added to bronze and is alloyed with aluminum to make these two substances tougher and more resistant to corrosion.

Manganese is added to steel in two forms. The first is known as ferromanganese and consists of an alloy of iron and manganese that contains about 80 per cent manganese. From 85 to 95 per cent of the manganese used in the manufacture of steel is added in this form. Nearly all of the remainder enters as spiegeleisen, an iron-manganese alloy that in the standard grade contains 20 per cent manganese. The manganese is used more efficiently and completely from ferromanganese than from spiegeleisen. For this reason, manganese from ferromanganese is much preferred by the steel manufacturers, although the cost of the manganese in spiegeleisen is only a little more than half the cost of that in ferromanganese. The cost of manganese is such a small proportion of the total cost of steel making that the increased efficiency is more important than the saving of fifty cents in the manufacture of a ton of steel.

Substitutes

Manganese is essential to the production of sound steel and no substitute has been found for it. Since, in a period of emergency, spiegeleisen can be substituted for a considerable amount of ferromanganese, it is possible to use lower-grade manganese ores. During the first world war the maximum amount of manganese used in the form of spiegeleisen was 16 per cent of the total used in the manufacture of steel. A few years after the war, however, the amount of spiegeleisen had decreased to only 4 per cent. It is also possible to replace a limited amount of ferromanganese with ferrosilicon, but there is no prospect of finding a satisfactory substitute for manganese in the metallurgy of steel. Some of the qualities of high-manganese steel are also imparted by molybdenum, and molybdenum steel may be used as a substitute for our manganese steel.

Technology

Spiegeleisen is made in a blast furnace in the same manner as pig iron, but the blast furnace is run at a somewhat higher temperature. The metal tapped from the furnace is simply an iron unusually high in manganese and is called spiegeleisen if it contains manganese in the range of 2 to 24 per cent. If it carries more manganese, it is known as ferromanganese; but the standard grade

for this latter metal is 80 per cent manganese. Although it can be made in a blast furnace, commonly it is made in electric furnaces because its temperature can thus be controlled more accurately. The loss of manganese in the blast furnace is extremely high. It has been estimated that approximately 40 per cent is wasted, about 32 per cent enters the slag, and 7 per cent goes up the stacks. The loss of manganese in the manufacture of ferromanganese is also extremely high, even when an electric furnace is used. Because of the great affinity of manganese for slag, it is desirable to use high-grade ores in the production of ferromanganese in order to reduce the waste.

Manganese is similar to iron in its occurrence, and a great many iron ores contain a considerable amount of manganese. Iron ores containing between 10 and 35 per cent manganese are classed as ferruginous manganese ores and may be used for the production of standard spiegeleisen if the ratio of iron to manganese is less than 2 to 7. Ores for standard ferromanganese are known as metallurgical ores of ferro grade, and the ratio of iron to manganese should be approximately 1 to 8. Ferro-grade ores commonly contain from 40 to 55 per cent manganese. During the first world war the standard for ferromanganese was reduced to 70 per cent. It thus became possible to use ores containing only 35 per cent of manganese. It is desirable to have less than 8 per cent silica and less than 0.25 per cent phosphorus in ferro-grade manganese ores; a penalty is imposed on ores that have larger amounts of these impurities. Manganiferous ores containing from 5 to 10 per cent manganese produce a high manganese pig iron that is much in demand.

The United States possesses little ore of ferro grade, and its reserves of spiegel ore are comparatively small. The United States Bureau of Mines has developed processes designed to turn large reserves of low-grade spiegel ore and manganiferous iron ore into sources of manganese for the steel industry. Several processes have been developed which may be used in an emergency when high prices prevail; but if adequate foreign sources of high-grade manganese ore are available, substantial subsidies might be required.

No secondary manganese is received as such, but some secondary manganese is recovered in the form of high-manganese scrap.

Manganese in ore is sold by the long ton unit of 22.40 pounds. The price paid per unit depends on the grade of ore: an ore containing 52 to 55 per cent manganese commands a few cents more per unit than one carrying 44 to 48 per cent manganese. Normally

an ore that has about 50 per cent manganese sells for 25 to 30 cents per unit, or at $25 to $30 a ton. In 1942, domestic production was subsidized through a premium price; when foreign ore of good grade was selling at 65 cents a unit of manganese, domestic ore of the same quality was being sold to the government f.o.b. the mines at $1 a unit.

Geology

Manganese is much like iron in its chemistry and its geology. It is widely distributed in nature and is known in more than a hundred minerals. It is found as a primary constituent of igneous rocks and sediments. Important primary types of manganese ore listed in the order of their importance include sedimentary ores, contact metamorphic deposits, and carbonate seams. The commercial deposits of manganese ore are due chiefly to weathering and enrichment of lower-grade primary deposits of silicates and carbonates and to residual enrichment of manganese oxides that, like iron oxides, are very resistant to weathering. Some of the best deposits are sediments derived from the erosion of residually enriched deposits. Although manganese deposits are widely scattered over the globe, those of commercial importance are largely confined to a belt between 45 degrees north latitude and 25 degrees south latitude. The areas that suffered extensive glaciation during the Pleistocene period are unlikely to contain workable manganese deposits. The great glaciers of the Ice age scraped off the soil and weathered rock over tremendous areas and laid bare fresh bedrock beneath. Any deposits of residual manganese ore that had been formed by weathering were relatively shallow in depth. Nearly all such deposits in glaciated regions were ruined by the advancing ice, which scattered the ores over hundreds of square miles as the glacier moved slowly forward. In the deposits that escaped destruction by the ice, residual manganese oxides are almost confined to the zone lying above the water table. In moderately humid climates this is generally less than 150 feet from the surface. As a result, a large number of manganese deposits are relatively shallow, and except for the sedimentary type the individual deposits are not long-lived.

Geology of some typical United States manganese deposits

Although approximately two thousand occurrences of manganese in the United States are recorded, the vast majority of them are not

of commercial interest. Only a very few deposits are capable of producing ferro-grade manganese ores without resorting to uneconomic methods of beneficiating the ore.

At Butte, Montana, large veins of manganese carbonate barren of copper minerals are associated with the great copper veins. Near the surface these veins have weathered into high-grade manganese oxide ore which formed an important source of ferro-grade manganese ore during the first world war. In 1939 the Anaconda Copper Company began to mine the primary ore and convert it into a high-grade manganese oxide by roasting. It is estimated that this area contains several million tons of carbonate ore and that Butte should be an important source of manganese during wartime. However, the high cost of transportation by rail from Montana to the eastern steel centers makes it difficult for Butte to compete with foreign sources during periods of peace.

At Phillipsburg, Montana, there is a moderate quantity of high-grade manganese ore in Paleozoic limestones. The deposits are lenticular bodies that resulted from the mineralization of limestone next to silver veins. It is estimated that 375,000 tons of ore containing 30 to 45 per cent manganese and about 125,000 tons of lower-grade ore are present.(8)

Batesville, Arkansas, is normally the most important source of manganese in the United States. The ore was formed through residual enrichment of a manganiferous shale of upper Ordovician age. The ore occurs as nodules of manganese oxide in clay derived from this formation by long-continued weathering.

In Virginia, Tennessee, and Georgia, manganiferous sediments are present in the Paleozoic rocks of the Appalachian Mountains at several horizons. The weathering of these sediments has yielded many small, shallow deposits whose occurrence is closely related to ancient erosion surfaces that are now commonly preserved as benches and hill tops of accordant level. These deposits have been worked for a long time and the reserves are not large.

Manganiferous ball-shaped concretions in the Pierre shale of Upper Cretaceous age are found at or near the surface through a great area near Chamberlain, South Dakota. The zone containing manganese is about 38 feet thick. At Chamberlain, concretions are from 3 to 8 inches in diameter and contain about 16 per cent of manganese and 11 per cent of iron. However, the material as mined contains less than 1 per cent manganese and must be concentrated before

it can be brought up to the grade of ferruginous manganese ore. The cost of such concentration is several times the normal cost of manganese ore.

The geology of a number of manganese deposits of the Southwest has been worked out by members of the United States Geological Survey in the past few years and a drilling program under the direction of the United States Bureau of Mines has revealed a large tonnage of low-grade ore in the deposits. Because of their distance from consuming centers, nearly all of this ore would be classed as marginal during normal times; they constitute, however, an important reserve that can be drawn on in times of emergency. The deposits are of Tertiary age and are related to volcanic activity. Both sedimentary deposits and veins are represented. Nearly all of the manganese ore produced in New Mexico has come from the Little Florida Mountains about ten miles southwest of Deming. In this district the veins contain primary quartz, barite (barium sulphate), and manganiferous calcite (lime carbonate) in volcanic rocks. Long-continued weathering has changed the manganiferous calcite into the characteristic black oxides of manganese that form the ore. As mined, the ore contains from 8 to 14 per cent manganese and must be concentrated. Reserves are not large.

Vein deposits with a similar geologic setting are found in the Paymaster district in southeastern California about thirty miles southeast of Blythe. In this district pre-Cambrian rocks have been faulted against the Tertiary volcanic rocks and conglomerate. Manganese oxides with some calcite occur as veins along the faults and in closely related fissures branching from the faults at angles of about 45 degrees. Much of the material contains less than 30 per cent manganese and is in veins not more than five feet wide. It would be necessary to concentrate most of this ore to bring it up to metallurgical grade. Exploration in this district has been meager, but reserves probably are not extensive.

A different type of manganese ore is illustrated by the Artillery Peaks and the Three Kids districts near Las Vegas, Nevada. In both areas, extensive deposits of low-grade bedded manganese ore occur in Tertiary lake beds. The sediments have been much faulted, however, and it is difficult to follow the ore horizons without detailed geology and diamond drilling. The best ore apparently runs about 35 per cent in manganese, but the reserves of this stock are small. Many millions of tons contain from 20 to 25 per

cent manganese, and in 1941 the United States Bureau of Mines began treating some of this ore in an experimental plant using power from Boulder Dam.

Large tonnages of manganiferous iron ore exist in the Cayuna range of northern Minnesota, and a substantial amount is also found in the Gogebic district of northern Michigan. These ores can be used in making manganiferous pig iron but are not suitable for spiegeleisen.

Important Sources of Manganese Ore

Cuba

Moderately extensive deposits of manganese lie in northern Cuba and have been worked for many years by American capital. The ore occurs as shallow replacements of gently dipping Tertiary sediments and volcanic rocks. The deposits are confined to the zone of weathering; although most of them bottom a short distance below the surface, some extend locally to depths of more than a hundred feet.

Brazil

The famous high-grade manganese deposits in the province of Minas Geraes, Brazil, are residual concentrations resulting from the weathering of pre-Cambrian schists containing manganese minerals. The ore is found in irregular lenticular masses and veins in the soft, decomposed, thoroughly weathered metamorphics. Most of the ore mined comes from Ouro Preto. Some of the lenses are as much as a half mile long, 1,000 feet wide, and 400 feet deep. Reserves of high-grade ore have been estimated at more than 10,000,000 tons. High-grade manganese ores are also known in the Matto Grosso region to the west. Brazil is becoming an increasingly important source of manganese for the United States.

Chile

Although Chile formerly produced manganese ore, she finds it difficult to compete with the excellent and comparatively cheap ores of Asia, Asia Minor, Africa, and India. The most important deposits are at Corral Quemada in Coquimbo. Manganiferous sediments occur interbedded with sandstone, shale, and volcanic flows.

Europe

Outside of the Soviet Union the iron and steel industry of Europe, like that of the United States, has had to depend on imported manganese. Belgium contains a few small deposits of weathered manganiferous iron carbonate, and some manganese ore has been mined from fault zones in Saône and Loire in France. Germany has a number of scattered deposits of manganese ore, which include small vein deposits in central Germany and Prussia and some lenticular deposits in Devonian limestones. Manganiferous iron carbonate ore containing about 6 per cent manganese occurs in large quantity in the Siegerland, Prussia. Production of this type of ore amounts to about 2,500,000 tons annually, but German ore of spiegel and ferro grade fills only a small part of the requirements of German iron and steel producers.

Manganese deposits recently exploited in Italy have shown a steadily increasing production. Deposits are found in Triassic sediments that contain a substantial amount of both manganese and iron. Deposits of residual manganese ore are scattered through many countries in Europe, including Spain, Rumania, Hungary, Bulgaria, and Yugoslavia. Although the deposits in them are normally of little importance, those found in Rumania and Hungary are supplemental sources of value to central Europe during times of emergency.

By far the greatest manganese deposits in the world are those found near Chiaturi in the Caucasus Mountains of the Georgian Republic of the Soviet Union. Here an Eocene bed of oölitic manganese oxides underlies more than 55 square miles of territory. The manganese bed is 4.5 to 7.5 feet thick and contains 7 layers that aggregate about 40 inches of nearly pure manganese dioxide. This deposit normally supplies nearly half the world's manganese ore.

At Nikopol north of the Black Sea a smaller but important bed of manganese oxide of Oligocene age furnishes a substantial amount of ore each year. The bed is from 1 to 5 feet thick and has been proved over an area of approximately 7.5 square miles.

India

The pre-Cambrian rocks of India contain many areas where a unique high manganese igneous rock has become deeply weathered and residual high manganese ore marks the outcrop. Some of the bodies are as much as 1,600 feet long, 500 feet wide, and 100 feet

deep. They occur in a belt 700 miles long that extends from Baroda on the west coast nearly to Calcutta. The largest deposit is at Bali Ghat where ore occurs in a shallow trough about 1.75 miles long and 25 to 50 feet deep. Because of the resistant nature of the manganese, it generally weathers in relief, and the ore caps low hills that stand up above the completely weathered barren schist near by.

The Philippine Islands

Recent explorations have uncovered large deposits of manganese ore which promise to contribute a substantial percentage of the world's production in the future. The ore is formed from the residual concentration of the manganese contained by innumerable veinlets that criss-cross certain igneous rocks.

Japan

Japan possesses many small contact metamorphic deposits in limy sediments next to igneous rocks. The commercial ores are due to residual concentration and enrichment of the primary ore. Reserves of this type are small. Most of the ore is mined on the Island of Hokkaido and near the town of Kyoto on Honshu Island.

Africa

Important deposits of manganese ore have been exploited in the Gold Coast by the American-owned Norwegian Electric Furnace Company. These deposits are due to the weathering of metamorphosed manganese-bearing sediments. The deposits are lenticular, but there is a large tonnage of ore available and a substantial amount is produced each year.

A central manganese field has been found near Postmasburg in the Union of South Africa. The ore occurs at the unconformity between the limy pre-Cambrian sediments and the overlying early Paleozoic rocks. The primary ore only contains 3 to 4 per cent manganese. Some manganese was concentrated by weathering before the Paleozoic rocks were laid down, but according to Du Toit, much of the important secondary manganese ore formed later.(4)

Consumption and Production

The consumption of manganese is in almost direct proportion to the production of steel. The leading consumers are therefore the leading industrial nations: The United States, Germany, Great

Britain, the Soviet Union, Japan, France, and Belgium. The Soviet Union is the only important consumer that is also an important producer. She alone among the steel-making nations exports manganese in quantity. The world production of manganese commonly ranges between 5,000,000 and 6,000,000 tons, and of this the Soviet Union supplies from 45 to 60 per cent. India commonly produces about 20 per cent of the world's total, and as she only consumes a small percentage of her own production, most of it is available for export. Germany, England, Japan, Belgium and the United States all draw upon India in peace time for part of their manganese supplies. The Gold Coast, the Union of South Africa, and Egypt together produce and export about 25 per cent of the world's manganese. Although the United States is normally the largest single consumer of African manganese, it takes only a little more than does Germany. Brazil has been fifth in the list of producers for several years, and the 250,000 tons mined annually is consumed almost entirely by the United States. Cuban ore moves to the United States exclusively. In the late nineteen-thirties, French Morocco and the Philippine Islands joined the ranks of important producers. (See Table XXXVII.)

The United States

Africa has provided only 5 to 10 per cent of the manganese consumed in the United States, which normally imports approximately 750,000 tons of manganese ore. It has been indicated earlier in this book that the United States has adequate supplies of low-grade ore but is notably deficient in ferro-grade manganese such as is required in making the ferromanganese regarded as essential by the steel manufacturers. Most of our imported ore comes from the Soviet Union, the Gold Coast, and British India. These three countries supplied approximately 60 per cent of our imports in 1940. The Union of South Africa, Brazil, the Philippine Islands, and Chile supplied nearly all the remainder.

Great Britain

The British steel industry is wholly dependent on imported manganese. As would be expected, England gets practically all her manganese from India. This major source of supply is supplemented by smaller shipments from the Soviet Union, Brazil, and the Union of South Africa. (See Table IX.)

TABLE IX

IMPORTS AND EXPORTS OF MANGANESE IN 1937 BY LEADING CONSUMERS AND PRODUCERS IN THOUSANDS OF METRIC TONS*

	Importers	*Exporters*			
	Soviet Union	India	Gold Coast	Union of South Africa	Brazil	Total
United States	384	70	255	19	78	926
Germany	61	121		290	12	554
Soviet Union	(1,700)					1,700
France	156	196	32	42	34	492
Japan	?(15)	179				252
Belgium	83	166	?(9)	55	22	340
Great Britain	14	242		15	14	288
Netherlands**	14	18		19	19	14
Norway	21	7	97			130

* (12; 14)

** Much of this ore was in transit to Germany and is not included in the total.

Germany

In peace time, Germany gets most of its manganese from the Union of South Africa and the Soviet Union. These major sources are supplemented by shipments from India, Brazil, and other countries. Germany, unlike England, can supplement her needs by domestic production of low-grade ores.

Political and Commercial Control

The political and commercial control of the largest manganese deposits in the world are identical, as the deposits in the Soviet Union are worked by the state. Most of the manganese that is produced outside the Soviet Union is under British political control, and most of the production is under British commercial control; however, the production of the Gold Coast is solely that of the African Manganese Mines Company, Limited, controlled by American capital. British interests control most of the manganese produced in India, Egypt, and the Union of South Africa. All the manganese produced in Cuba and most of that produced in Brazil is in the hands of American companies; less than half the Brazilian output was controlled by local capital in 1940. Most of the manganese mined in the Philippine Islands has been taken out by native companies, but the largest single producer in 1941 was an American company.

It is apparent that most of the world's manganese was controlled by Russian, British, and American interests in the years preceding the second world war.

Influence on National Policies

Manganese ores are so widely scattered over the face of the globe that it is difficult for any one group to obtain a monopoly on manganese production. For this reason, the industries of the United States have not been greatly concerned about the commercial control of manganese deposits, most of them having been satisfied to obtain manganese in the open market. American capital has been invested in the manganese deposits of Cuba, Brazil, and the Gold Coast because they were good commercial investments. However, with the approach of the second world war, the federal government became increasingly concerned with providing an adequate supply during the approaching national emergency. It pursued several policies: money was made available to the United States Geological Survey to search for manganese in the United States and in the Latin American countries; funds were also appropriated for the Bureau of Mines to explore manganese deposits mapped by the Geological Survey and to estimate tonnage and grade; efforts were made to accumulate a stockpile from foreign sources that might be cut off during the war—a stockpile sufficient to assure the steel industry of adequate supplies during the emergency. Increasing efforts were made to stimulate production in the Latin American countries. This procedure had two objectives: It furthered the Good Neighbor policy, and it provided sources of manganese that were less accessible to the U-boat campaign of the Axis powers than were those in Africa and Asia. After the discovery and exploration of the manganese deposits of the United States had been carried out by the federal bureaus, money was also made available by the government for their development by private companies. There is always, however, a notable lag between discovery and production, and this lag occurred when the need was critical.

Germany's deficiency in manganese led her to develop thoroughly the low-grade deposits whose exploitation was uneconomic except during a period when outside sources of manganese were shut off. Chief reliance, however, was placed in a stockpile that had gradually accumulated during a period of several years preceding the second world war.

The great manganese deposits of the Caucasus Mountains, together with the oil fields around the Caspian Sea, have long been regarded with a hungry eye by the manganese- and petroleum-starved industrial regions of central Europe. The Soviet Union

exported as much manganese as was necessary to provide her with the "valuta" (foreign exchange) necessary to finance purchases abroad for her program of industrial expansion. In some years, especially during 1932–1933, her exportation policy led to "dumping" ore on the market in such quantities that many other leading producers were forced to cut their production to almost nothing. Later this policy was abandoned, and trade during the late thirties seemed to represent a fairly equitable distribution of production among the leading world sources. As has already been noted, the Soviet Union for many years stockpiled manganese in the interior to provide for the steel industries of Siberia in the event that she might lose the Caucasus to hostile powers or be cut off from her steel centers.

Since the United Kingdom has no low-grade manganese ores as does Germany, it has been completely dependent on imports for all manganese ore. It has long been the British policy to prevent foreign capital from acquiring possession of its minerals. As a result, the manganese deposits of the British Empire are largely in the hands of British subjects. France has encouraged the development of manganese deposits in her colonial possessions in North Africa with a considerable degree of success, especially in French Morocco. Belgium, likewise, has sought to develop the manganese deposits of her vast empire in Africa. However, though deposits of manganese are known in the Belgian Congo, they have not yet been developed. Belgium would in any event be dependent on imports of manganese from her own possessions or from other countries.

Japan's deficiency in manganese has led her to import manganese steel scrap and to hunt for manganese deposits in neighboring countries. Japanese ore buyers have been active in the Philippine Islands for many years, and the character and location of the Philippine manganese deposits were well known to the Japanese before the invasion in December, 1941. Prior to the war, she had acquired a large supply of manganese. The stockpiles of deficiency minerals that Japan built up in the years prior to the war were larger than the technical experts of the United Nations estimated; this reserve was very properly called Japan's most terrible "secret weapon."

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CHAPTER 10

Chromium

Properties and Uses

A LITTLE LESS THAN half the chromium produced is used in the metallurgical industries. Approximately two-fifths is used as a refractory, and the remainder is consumed by the chemical industry. Chromium imparts strength, toughness, hardness, resistance to abrasion, resistance to chemical corrosion, and high electrical resistance to steel. These qualities are retained at much higher temperatures in chrome steel than in steels with similar properties made from other alloy metals. As a result, chrome steels have made possible certain industrial developments that could not otherwise have taken place. The strength and resistance to corrosion at high temperatures is essential to modern oil refinery stills. The amount of chromium used varies with the purpose of the steel. The low-chromium steels, which contain less than 5 per cent of chromium, are used in automotive work and for armor plate and armor-piercing projectiles. The intermediate chromium steels, containing from 3 to 12 per cent chromium, generally contain other alloying elements such as molybdenum, silicon, or tungsten and have many uses. They make excellent high-speed tool steels, valves for engines, and a variety of equipment that requires some resistance to corrosion and oxidation. The stainless steels contain from 12 to 18 per cent chromium, and the so-called super-stainless steels contain from 12 to 30 per cent chromium and generally from 7 to 10 per cent nickel. The maximum resistance to oxidation at high temperature is found in steels that carry from 20 to 30 per cent chromium; such steels are used for various types of chemical and surgical equipment. Chromium-nickel-iron alloys that fall in this class are also extensively used in the resistance elements of electrical heaters. Chromium-cobalt alloys containing 20 to 35 per cent chromium with the remainder made up of cobalt and some tungsten are used in limited quantities for making an extremely hard

alloy which finds important use as a surfacing metal on parts that are subjected to unusually hard wear by abrasion. It should be pointed out that the growing use of steels containing large amounts of chromium increases the demand much more rapidly than does an expansion in the market for low-chromium steel. Just one ton of super-stainless steel would require as much chromium as ten or twenty tons of low-chromium steel.

Chromite, the only ore of chromium, is an exceedingly inert and refractory material. It finds an important use as a lining for furnace construction and is used to separate an acid roof from a basic hearth, thus preventing a reaction between the two at their contact. About one-sixth of the chromium produced goes to the chemical industry. Here it enters chromates, dichromates, and other chemicals that are used in the tanning industry and as a base for some of our most permanent dyes and pigments. The oxides and sulphates are used for making up baths for chromium plating. So resistant is the pure metal that is used for electroplating on steel that a film from two-millionths to five-millionths of an inch thick is sufficient to protect the iron from oxidation and wear.

Substitutes for Chromium

Chromium is one of the most indispensable of the ferro-alloy metals. Although certain other alloy steels can be used as substitutes for many of the low-chrome steels, it is difficult if not impossible to find substitutes for chrome steel in equipment that is subjected to chemical corrosion at high temperatures, especially if strength is also a requisite under the operating conditions. Nothing is as satisfactory for electrical resistance furnaces as nickel-chromium alloys unless it is prohibitively expensive materials such as platinum and irridium. Magnesite may be used in place of chromite for furnace linings unless the neutral brick is required. Where a chemically inert substance is needed, no satisfactory substitute has yet been found for chromite in the refractory trade. As yet, no satisfactory substitute has been found for chromium in the tanning industry. There are, of course, many substitutes for chrome pigments in dyes. The great tensile strength of chrome steel has made it possible to use metal parts of such small diameter that some chrome steel competes successfully with aluminum in the airplane industry. It is obvious that for such uses aluminum can be substituted for these chrome steels.

Technology

Chromium is produced from chromite, a ferrous chromate which may contain as much as 68 per cent chromic oxide and 32 per cent ferrous oxide. However, in some pure chromites a certain proportion of chromic oxide has been replaced by ferrous oxide. For this reason it is possible to have chromite ore, free from any waste minerals, that contains as little as 30 per cent chromic oxide. Since much of the chromite in the United States unfortunately belongs to this class of high-iron chromite, it is unsatisfactory as a chromium ore. The so-called "high-grade chrome" ore that the steel industry uses contains from 45 to 55 per cent chromic oxide or 30 to 36 per cent chromium metal. Ore of this grade normally sells at about $20 per long ton on the Atlantic seaboard. In 1942 both domestic and foreign ore of standard grade (48 per cent chromic oxide, chrome to iron ratio 2.8 to 1) brought approximately $40 a long ton.

For metallurgical use, chromium is converted into a high-chromium iron alloy known as ferrochromium. Standard ferrochromium carries 65 to 70 per cent chromium and normally sells for about 10 cents per pound of contained chromium. In 1942 the price in the United States was held at 13 cents per pound of chromium. As silica enters readily into the ferrochromium, it is a most objectionable impurity in chromite ores. Other impurities that are commonly present are objectionable chiefly because they require additional flux for their elimination and thus increase the cost of smelting. For metallurgical use the ratio of chromium to iron that is desired is approximately 2 to 1, but for refractory use the ratio should be even higher. The lower the ratio of chromium to iron, the more easily does the material fuse and the less desirable is it for a refractory brick. Chromite of refractory grade should have part of the ferrous iron replaced by magnesium. As the composition of chromites from given localities is likely to be fairly constant, the suitability for a particular use is determined for each source before it is accepted by the trade. Once a satisfactory source of chromite is found, the various divisions of the industry are extremely reluctant to change to new ones. Normally there is enough high-grade chromite ore in the world to supply all demands without resorting to concentration. However, during wartime, low-grade chromites in the United States have been crushed, washed, and mechanically concentrated into a much higher-grade product.

Standard ferrochromium contains from 66 to 72 per cent chromium, less than 2.5 per cent silicon, and minor amounts of manganese and carbon. The refractory nature of chromite makes the ordinary blast furnace unsuitable for reducing this ore. Very high temperatures are easily attained in electric furnaces and nearly all ferrochromium is made in this type of equipment. A small amount is produced by the so-called thermic process in which chromic oxide is reduced by powdered aluminum. An extremely high temperature is generated by the oxidation of the aluminum and the reduction of the chromic oxide. This process is used where a very low carbon content is desired.

Although very little pure chromium is recovered as scrap metal, the chromium content of chrome steels is reused in scrap. A small percentage of chromium in scrap makes it much more valuable, and the high price that it commands results in an unusually high recovery of secondary chromium from this source.

Geology

All chromite deposits known are associated with mafic igneous rocks or their metamorphosed equivalents. Chromite is a heavy mineral which crystallizes early in the solidification of an igneous rock and settles out readily as a magmatic segregation. This explains its invariable association with the low-silica iron-rich minerals of high melting point, such as olivine (peridot). All the chromite deposits in the United States investigated by the Geological Survey are found in masses of the olivine-rich rocks known as peridotite. The masses of peridotite are usually associated with other mafic igneous rocks rich in the mineral pyroxene and with some feldspar content.

The chromite itself occurs as lenses, pods, and irregular masses, and in grains disseminated through the rocks. Chromite ore bodies are especially common along the bottom and borders of igneous masses and some ore bodies are found in dikes.

The resistant nature of chromite makes it lag behind long after the other minerals of the peridotite have weathered. The residual concentrations of chromite ore at the surface are important sources of chromite, especially where chromite-bearing peridotites are exposed to a humid climate. Sediments derived from such outcrops also may be rich in chromite. Placer deposits have been an important source of this mineral in many regions. Near the surface the olivine rocks are usually altered to soft magnesian minerals

such as talc and serpentine, and from them the hard resistant chromite is easily separated.

Important Sources of Chromite

Soviet Union

Most of the chromite produced by the Soviet Union comes from the Ural Mountains about midway between the Aral Sea and the Arctic Ocean. In the Perm district about 150 miles northwest of Sverdlovsk is the Saranovskoe district. (See Figure 31.) Here ultramafic rocks rich in chromite have been intruded into metamorphosed Paleozoic beds. The intrusive rock is a strongly serpentinized peridotite, and three bands of ore are found in it that are from 13 to 30 feet thick. The peridotite intrusions and the bands of ore are nearly vertical, and the ore has been proved to a depth of several hundred feet. Large masses of diabase, a much less mafic rock, are associated with the peridotite. The stream beds draining the area contain valuable deposits of placer chromite. Reserves of placer and bedrock ore are estimated at nearly 7,000,000 metric tons. Although the chromite contains only 35 per cent of chromium oxide, it is valuable because it is a magnesian variety containing almost no iron.

Rhodesia

Perhaps the most unusual body of igneous rock in the world is found in Southern Rhodesia where the "Great Dyke" extends north and south for a distance of more than 300 miles. This dike is from 3 to 4 miles in width and reaches to a great but unknown depth. It is made up of a variety of mafic and ultramafic rocks, and associated with many of them are sheets and lenticular masses of chromite. Some of the chromite deposits lie outside the Great Dyke but are not far distant from it. They probably were formed by magmatic solutions emanating from the Great Dyke itself. Much of the ore is in gently sloping seams from 8 to 30 inches thick. The ore adjacent to the dike occurs as lenses in schist made up of serpentine, talc, and related minerals. The best-known district along the Great Dyke is at Selukwe about 585 miles from Beira, Portuguese East Africa, the nearest shipping point. Most of the lenses in the Selukwe district range from 150 to 450 feet in length and contain about 51 per cent chromic oxide, 12 per cent iron oxide, and 15 per cent magnesium oxide.

The Union of South Africa

In the heart of the Union of South Africa is one of the most unusual masses of igneous rocks in the world. It is known as the Bushveld Complex and comprises many different types of mafic and ultramafic igneous rocks arranged in nearly flat-lying sheets that have the characteristics of an igneous sediment. Some of these rock masses contain chromite and platinum. The chromite is associated with olivine and another iron silicate known as bronzite. The iron content of the chromite is relatively high, but the ore that is shipped contains about 32 per cent of chromic oxide.

The chromite of the Union of South Africa can be marketed at a lower price than the Rhodesian ores because of the lower transportation and mining costs.

The United States

Chromite deposits are widespread in California and southern Oregon, but in only a few of them have substantial reserves been proved. Although the deposits differ greatly in detail, most of them belong to the same general class; therefore a description of the Pillikan area may be taken as typical of the deposits. The *Pillikan district* is about 12 miles south of Auburn in Western Eldorado County, California. The chromite deposits are confined to an elongate, steeply dipping, tabular body of ultramafic rocks about 4 miles long and three-quarters of a mile wide which trends nearly north-south and dips steeply east. The rocks are irregularly layered and in some places have been altered to serpentine, talc, and other secondary minerals. The chromite ore is confined to the olivine rock (dunite) and occurs as disseminated grains, as clusters of crystals, or as layers of nearly pure chromite. Some of these layers are as much as 2 or 3 feet thick. Ore of this sort can be mined and shipped without concentrating, but the importance of the deposit now lies in the production of lower-grade ore that may be crushed, concentrated, and shipped. The ore mineral contains from 30 to 45 per cent of chromic oxide, and thus the purest concentrate obtainable could hardly contain more than 45 per cent of chromic oxide. According to Wells, Page, and James, there are at least 550,000 tons of ore containing more than 20 per cent of chromite, 4,000,000 tons of ore containing from 10 to 20 per cent of chromite, and a very large tonnage of rock containing less than 10 per cent.(15)

Stillwater Complex, Montana. In Stillwater County, about 15 miles south of Big Timber, Montana, a remarkable series of ultramafic rocks occur, which have many features in common with the Bushveld series of South Africa. This series has been called the Stillwater Complex; like its African cousin it contains chromite. The Stillwater Complex is exposed in a belt from 1 to 5 miles wide and 30 miles long extending in a west to northwest direction along the northern border of the Beartooth Mountains. The chromite occurs about midway between the top and bottom layers of the ultramafic rocks, which are composed chiefly of olivine and pyroxene. It is probable that the layers were nearly horizontal when the chromite, olivine, and pyroxene were crystallizing from the molten igneous mass in pre-Cambrian time. Detailed work by Peoples and Howland, together with drilling by the Bureau of Mines, indicates a tremendous tonnage of submarginal ore that can be recovered from this deposit in time of need.

Like the chromite of the California deposit described previously, the chromite of the Stillwater Complex contains only about 45 per cent of chromic oxide. In some places the chromite is concentrated in a single layer of chromite-rich rock from a few inches to 5 feet thick and in other localities there are alternate layers of chromite-rich and chromite-poor rock through a thickness of as much as 50 feet. Locally, several zones of this sort are separated by layers of barren rock. It is probable that the chromite continues to a depth of several thousand feet with no more variation in grade than appears at the surface. To be used, such ore must be concentrated, but in 1942 it was one of the most important sources of chromite in the United States. Although millions of tons of concentrating ore are available, it would be difficult to exploit the deposits profitably when African chromite was available to the eastern seaboard.

Production and Consumption

The production of chromite is commonly about 1 per cent of the production of steel. The chief consuming nations are of course the chief industrial nations, and the demand is nearly proportionate to the steel output. Aside from the Soviet Union, all the steel-producing countries are dependent upon imports for their supply of chromite. The centers of chromite production have shifted widely since the mineral was first mined. Until 1830, Russia produced most of the chromite used. The discovery of many small

chromite deposits in Pennsylvania and Maryland made the United States the leading producer of chromite from 1830 to 1870, when the opening up of the rich deposits of Turkey and Asia Minor made that region the chief source of chromite in the world until 1900. Production of the American deposits dropped rapidly, and our deficiency in this mineral is now so great that it is difficult to realize that we were once the leading producer in the world. The shallow, easily worked deposits of New Caledonia made this French island the leading producer of chromite from 1900 to 1920. The African deposits then caused another major shift. Rhodesia dominated the world markets throughout the nineteen-twenties, but after 1930 Russia again became the leading producer of chromite and has maintained its leadership.

The *Soviet Union* has large reserves of chromite in the Ural Mountains and formerly exported a substantial quantity of this mineral. Since 1935, however, her exports have been nil; and although no production figures are available for 1936–1941, it is probable that she has increased her production substantially over the 217,000 metric tons recorded for that year. How much of this chromite went into a stockpile is difficult to say. *Southern Rhodesia*, the second largest producer, furnishes from 15 to 25 per cent of the world's supply in normal times. Commonly from one-half to two-thirds of the Rhodesian ore finds its way to the United States via Mozambique. *Turkey* usually produces only a little less ore than Rhodesia, and in some years exceeds its southern competitor. Germany is the best customer for Turkish chromite and commonly takes from two to five times as much as that obtained by France and the United States, her next-best customers. The *Union of South Africa*, the fourth largest producer, was not important until 1935 when her production approached 100,000 tons. Since that time she has produced annually between one-sixth and one-ninth of the world's chromite. The United States commonly takes about one-half the production of the Union of South Africa. Germany took between one-third and one-fourth, and Great Britain absorbed most of the remainder. There are many small deposits of chromite in *Greece* and *Yugoslavia* whose production in total makes a substantial part of the world's output. Each of these countries during the late nineteen-thirties produced between 50,000 and 60,000 metric tons annually. As would be expected, Germany was the best customer for this ore, but Great Britain and the United States took a substantial part of the production of Greece. *Cuba* has for many years

TABLE X

PRODUCTION AND CONSUMPTION OF CHROMITE BY THE LEADING INDUSTRIAL NATIONS(3)

Country	*Production*	*Imports*	*Consumption*	*Chief Sources*
United States				
1935	515 L.T.	259,063 L.T.	259,578 L.T.	Rhodesia (Mozambique), Cuba, French Oceania
1937	2,321 " "	553,916 " "	555,237 " "	Rhodesia (Mozambique), Cuba, Union of S. Africa
1939	3,614 " "	317,511 " "	321,125 " "	Philippines, Cuba, Union of S. Africa, Mozambique
United Kingdom				
1935		25,832 M.T.	36,061 M.T.	Greece, South Rhodesia, Turkey, India, Union of S. Africa
1937		44,853 " "	63,004 " "	Union of S. Africa, Greece, South Rhodesia, Portuguese E. Africa
1939		50,620 " "	65,437 " "	Union of S. Africa, South Rhodesia, Greece, India
Soviet Union				
1936	219,000 M.T.		220,000 M.T.	Soviet Union
Germany				
1935		95,440 M.T.	95,440 M.T.	South Rhodesia, Union of S. Africa, Turkey
1937		132,162 " "	132,162 " "	Turkey, South Rhodesia, Union of S. Africa
1939*		136,434 " "	136,434 " "	Turkey, Union of S. Africa, Greece
France				
1936		46,823 M.T.	46,823 M.T.	Turkey, Greece, Yugoslavia, New Caledonia
1937		38,171 " "	38,171 " "	
1939*		32,632 " "	32,632 " "	

TABLE X (*Cont.*)

Country	*Production*	*Imports*	*Consumption*	*Chief Sources*
Italy		About 25,000 M.T. annual import and consumption		Turkey, Albania
Japan				
1936	39,100 M.T.	3,400 M.T.	42,500 M.T.	Japan, Philippines, New Caledonia
		(Figures are approximate only)		
1940	?	32,550 " "	?	(Japan?), Philippines
World				
1935	790,000 M.T.		790,000 M.T.	Soviet Union, Turkey, South Rhodesia, Union of S. Africa
1937	1,300,000 " "		1,300,000 " "	South Rhodesia, (Soviet Union?), Turkey, Union of S. Africa
1940	1,250,000 " "		1,250,000 " "	(Soviet Union?), South Rhodesia, Philippines, Union of S. Africa

* Figures for first 7 months only.
Chief sources are listed in order of importance down to 10 per cent of total.

exported from 40,000 to 90,000 tons of chrome ore to the United States annually. The deposits are in the hands of a few American companies; the reserves are large and production could easily be doubled.

Exploitation of the *Philippine* chrome ores began in 1935, and with the advent of modern American mining methods in 1937, the production increased until in 1940 nearly 200,000 tons of chrome ore were exported. Three-fourths of this ore came to the United States, and Japan took most of the remainder. *New Caledonia* commonly produces between 50,000 and 60,000 tons of excellent chromite annually, and the United States takes most of it. *India* also produces about 50,000 tons annually, and this ore is exported chiefly to Great Britain, the United States, Norway, and Germany. The exports to Norway are processed by electric furnaces into ferrochrome, which is re-exported to the steel-producing countries.

Political and Commercial Control

British capital controls the production of chromite in the Union of South Africa and India, most of the output in Southern Rhodesia and Yugoslavia, and nearly one-half that of New Caledonia. It should be noted that a substantial amount of American capital is invested in British companies that operate in Africa. American capital controls slightly more than one-half the production of New Caledonia, all the production of Cuban chromite, and nearly all the production of Philippine chromite. German companies produced most of the chromite in Turkey and a small amount of that in Yugoslavia before they took over the latter country in 1941. At this time a substantial amount of the chromite produced in Greece and Yugoslavia was controlled by French capital and a small amount of the chromite produced in New Caledonia and Turkey was also under French control. As commercial and political control of Russian chromite is identical, it appears that Great Britain, Russia, and the United States controlled all but a very small part of the world's chromite production in 1940.

National Policies

When the heavy shadow of the second world war fell across the United States, the government began an extensive campaign of exploration and development of domestic chromite. Prospects and mines were tested, and the development of these properties was encouraged in many ways. Money was loaned, priorities on ma-

chinery granted, free consulting work by experts was made available, and some large, well-financed, experienced mining companies were induced to operate on what was virtually a cost-plus basis. Geological surveys and drilling campaigns were carried on in the western states and Cuba. Some of the Latin American countries were also investigated. So far as is known, no large government stockpile was built up, but the steel industry had acquired a reserve before the war and some African chromite came through in spite of the U-boat campaign.

The Soviet Union assures self-sufficiency by mining enough to have an exportable surplus. The other industrial nations, lacking chromite within their borders, have taken whatever means seemed most expedient to insure access to areas exporting the raw material for making this invaluable ferro-alloy metal. To Germany, this meant south-eastern Europe; to Great Britain, it meant Africa.

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CHAPTER 11

Nickel

Properties and Uses

NICKEL and its alloys are tough, strong, and unusually resistant to chemical action. About 60 per cent of the nickel used goes into nickel steels, and the remainder goes into alloys of copper, aluminum, and other metals. In general it may be said that nickel alloys are among the most satisfactory known for parts subjected to corrosion, shock, temperature changes, heavy loads, and abrasion. The low-nickel steels (0.5 to 0.7 per cent nickel) are ductile, strong, and tough; they are popular in the automotive, aircraft, and railway construction industries for axles, frames, connecting rods, and many other pieces of equipment. Low-nickel steels are also used in many types of heavy-duty machinery and in construction shapes. High-nickel steels (7 to 35 per cent nickel) are corrosion resistant and heat resistant. Such steels are used for furnace parts, marine construction of many sorts, chemical apparatus, cooking utensils, and trim. Some high-nickel steel alloys have an extremely low coefficient of thermal expansion and are used for making length standards, precision instruments, and various devices for the control of temperature and electric current. A large amount of nickel steel went into armor in the first world war, and it is still much used in the manufacture of armor plate, although some of our modern armor contains a substantial amount of chromium. Nickel steels are extensively used for making gun forgings, bullet jackets, and recoil springs as well as for armor plate.

Nickel is the chief constituent of a very highly magnetic alloy specified for sheathing submarine cable, radio, and various types of transformers, and strangely enough it is also an essential constituent of the nonmagnetic alloys required for certain uses in the electrical industry.

Monel metal, a strong noncorrosive, copper-nickel alloy containing 67 per cent nickel and 28 per cent copper, together with minor amounts of ferromanganese, silicon, and carbon, is a strong non-

corrosive alloy popular for use in marine engineering, food preparation and service equipment, hospitals, laundries, and a multitude of mechanical-equipment industries. Nickel is added to bronze and brass when an exceptionally strong corrosion-resistant alloy is required.

Because of its resistance to corrosion, nickel plating is often used on such metals as steel, brass, copper, and zinc. The thickness of the plate ranges from 0.0001 to 0.001 inch, but the process is so popular that a substantial tonnage of nickel is consumed in the nickel-plating industry.

Nickel is finding increasing use in food utilization equipment, in the chemical industry—where it is especially used in the manufacture of alkaline storage batteries—and in the ceramic industry. A small amount of nickel is also used in the coins of many countries.

Substitutes for Nickel

Chromium steels are the most logical substitutes for many of the nickel steels, but they are more expensive. Cadmium plating or chrome plating may be substituted for nickel plating. No satisfactory substitute for nickel bronze and nickel brass exists, but it is possible to revert to the former practice of using the standard alloys and replacing the parts more frequently. Molybdenum can be used as a substitute for nickel in the manufacture of ductile steel. Manganese steel can be substituted for nickel steels whose chief requirement is resistance to abrasion.

Technology

Most nickel is produced from an ore containing nickel sulphides associated with copper sulphides, and almost all the remaining ore produced comes in the form of a mixed silicate of nickel and magnesium. The two types are treated somewhat differently.

Garnierite, the nickel mineral of the silicate ores, is mixed with gypsum (lime sulphate) and smelted in a blast furnace. Part of the iron in the ore is slagged off at this stage, but most of it combines with nickel and sulphur to form matte, a mixture of iron and nickel sulphides. The matte is oxidized in a Bessemer converter where all the iron sulphide is converted to iron oxide. As the iron oxidizes before the nickel does, it is possible to stop the operation at a point where the iron is oxidized and the nickel is still present in the form of sulphides. At this stage, the iron oxide unites with a flux that has been added to form slag which can then be drawn off

from the charge leaving only nickel sulphide. It is roasted to eliminate the sulphur, and the resulting nickel oxide is reduced with carbon in an oil-fired reverberatory furnace. This metal may be further purified by electrolysis or other processes.

Sulphide ores are treated somewhat differently from silicate ores. They are first roasted in a reverberatory furnace to eliminate some of the sulphur and iron and are then blown in a Bessemer converter to eliminate all the iron sulphide. The resulting nickel-rich matte is roasted to nickel and copper oxide. These oxides are either reduced in a reverberatory furnace to a copper-nickel alloy (Monel metal) or, if the Oxford process is used, the copper-nickel matte from the converter is fused with sodium sulphide in which the copper sulphide is soluble. The molten sodium-copper sulphide floats on top of the heavy insoluble nickel sulphide melt and can be easily separated from it. The nickel sulphide is then roasted to the oxide and reduced to metallic nickel.

The recovery of scrap nickel is increasing yearly but is far below what is possible. It represents only about 10 to 14 per cent of our annual consumption.

Geology

Few commercial deposits of nickel exist, and all are associated with mafic rocks. A small amount of nickel is usually found with chromite and with iron ores derived from the weathering of mafic rocks such as are present in Cuba. The nickel was originally present in these rocks as a primary igneous mineral, and it was formerly thought that the primary ore of all our commercial deposits was formed as magmatic segregations. However, it now seems probable that some of the sulphide ores found at the edge of mafic intrusions are more properly classed as veins rather than segregations.

Important Sources of Nickel Ore

Canada

The Sudbury nickel region of Ontario is about 250 miles east of the Sault Sainte Marie. It is the greatest nickel-bearing area known and produces about 85 per cent of the world's nickel. A north-northeast-trending canoe-shaped body of mafic rock (norite), 36 miles long and 20 miles wide, intruded metamorphic rocks here in late pre-Cambrian time. Some 40 nickel mines are spotted along the contact between the intrusive and the older rocks. The Creigh-

ton mine, nine miles southeast of Sudbury, and the Freud mine, three miles to the north, produce most of the nickel and are believed to have reserves capable of furnishing the major part of world requirements for several decades. The ore in the Creighton and most of the other nickel mines is found at the base of the westward-sloping mafic rocks. The ore minerals are intergrown with silicates of the igneous rocks to a considerable distance from the contact. In the Creighton mine, patches of ore are found extending as much as 2,000 feet into the norite. In the Freud mine, the ore body is east of the main norite contact, and the ore lies within the metamorphosed sediments and lavas. Mineralogically it is similar to the ore bodies to the west. In addition to the abundant copper, iron, and nickel sulphides a small amount of platinum and gold is present. Platinum makes a valuable by-product in the winning of copper and nickel from this district.

New Caledonia

Some of the mafic igneous rocks of New Caledonia carry an appreciable amount of nickel. In the long period of weathering to which these rocks have been subjected, much of the nickel has been concentrated as nickel silicate (garnierite) close to the surface. This material commonly carries 4.5 to 6 per cent nickel and is easily mined. Until the turn of the century, New Caledonia was the leading nickel producer of the world; but from that time on Canada dominated the field.

Norway

There are many areas of mafic rocks in Norway where small nickel deposits occur. Their geology is similar to that at Sudbury, except that all the deposits found have been small and the reserves are not large. It should be remembered, however, that a considerable proportion of Fennoscandia is covered by glacial drift and that the possibility of finding a substantial producer exists. A nickel mine at Evje, in southern Norway, produces about 1,500 metric tons annually and accounts for virtually all Norwegian production. However, it would be possible to draw on some of the properties that have been inactive for many years if it seems important that Norway increase her production. The second most important property is at Nakkarud, about 25 miles northwest of Oslo.

Finland

The largest nickel deposit known in northern Europe is near Petsamo in northern Finland. American capital undertook the development of this deposit, and a substantial reserve of copper and nickel sulphides was proved that averaged about 3 per cent nickel and 1 per cent copper. Operations were interrupted by the Russo-Finnish war, but it is believed that the property was brought into production in 1942 by the Finns with German aid. The American engineers had expected to produce about 10,000 tons of nickel annually and about 3,000 tons of copper.

The Soviet Union

Nickel has been discovered in some of the many areas of mafic rocks in the Ural Mountains, but the deposits found prior to the second world war were of relatively low grade. The Soviet's production is about on a par with that of Norway.

Greece

There are several small nickel deposits in Greece. The principal one is at Larmma, east of Atalanti, and is reported to have reserves of 500,000 tons of 2.5 per cent nickel ore. The nickeliferous iron ores of Greece, Cuba, Borneo, and the Philippine Islands are more desirable than ordinary ore but cannot be regarded as a source for metallic nickel.

Production and Consumption

The United States normally consumes about half the world's production of nickel; the Soviet Union about 15 per cent; Germany, about 10 per cent; and the United Kingdom, about 8 per cent. The annual production of nickel for the world has climbed steadily since 1932, which recorded the lowest production since 1921. Nickel production increased from 20,000 tons in 1932 to nearly six times that figure in 1940. Canada has consistently supplied about 85 per cent of the total, and New Caledonia about 10 per cent.

Commercial and Political Control

The nickel industry of Canada is controlled jointly by British, Canadian, and American nationals. The proportion which should be credited to each shifts from time to time, but the participation

of United States capital was slightly less than 50 per cent throughout most of the decade 1930–1940.

The International Nickel Company dominates the nickel production of the world. It was formerly controlled by American capital, but when it consolidated a few years ago with its chief rival, the British-owned Mond Nickel Company, the amount of American participation was materially reduced. The company has smelting and refining plants in both Canada and Great Britain and extensive fabricating plants in the United States. The Falconbridge Nickel Mines Limited is the second largest producer in Canada and normally refines most of its products at Christiansand, Norway, where it owns a large refinery.

French and Belgian capital controls the production in New Caledonia, but the concessionaires producing the ore included both French and Japanese during the nineteen-thirties.

National Policies

For all countries in the world except Canada, nickel is regarded as a strategic mineral of the first importance. In spite of the concern with which nickel is regarded by the military of the United States, there seems little need for anxiety in this country. The common interest of the United States and Canada is now so apparent that an adequate nickel supply from the world's greatest nickel district seems assured. The possibility that Canada would sever diplomatic relations with the United States and cut off our nickel supply seems no more likely than the possibility of a revolt in northern Minnesota and the consequent cessation of the iron ore supply from that region. If either contingency arose, it is probable that the same method would be invoked to reopen the supply.

Since Germany has no domestic production of nickel, it must depend on outside sources. When the Canadian supply is eliminated, Germany must look to Norway, Finland, the Soviet Union, and Greece as possible sources to supplement her stockpile. In 1941, German technicians continued the development of the Petsamo deposits in Finland started by the engineers of the International Nickel Company of Canada. Italy, Germany, and Japan all endeavored to provide adequate stockpiles of the metal before the Canadian supply was cut off by the second world war.

The Soviet Union has not been thoroughly explored, and it is quite possible that large enough nickel deposits will be found to satisfy

her domestic requirements. In spite of strenuous efforts of the Soviet's geologists and mining engineers, she was still far from attaining self-sufficiency when Germany launched its attack against her in 1940.

The geography of nickel production is shown in Figure 34, facing page 262.

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CHAPTER 12

Tungsten

Properties and Uses

TUNGSTEN has an unusually high melting point and great tensile strength. The pure metal melts at about 3,500 degrees C. (6,100 degrees F.) and has a tensile strength of 450,000 pounds per square inch. Used in alloys, it imparts the qualities of toughness, strength, hardness, and resistance to abrasion even at high temperatures. Tungsten is a very hard metal, and its carbide is second only to diamond in hardness.

Tungsten finds its widest and most important field of use in alloy steel. The introduction of tungsten steels forty years ago revolutionized the metal-cutting industries. Tools made from tungsten steel were found to last many times as long as the best tools made previously, and the efficiency of the worker was increased from 3 to 5 times. The so-called high tungsten steels, which contain from 15 to 20 per cent tungsten and 4 or 5 per cent of chromium or molybdenum, retain their cutting edge and temper at red heat. It is possible with tools of such an alloy to run lathes and other metal-cutting machines at speeds that would be impossible otherwise, hence the common name, "high-speed steel." The same qualities that make tungsten steel so well adapted for tools make it desirable for many other special uses. It is one of the best materials for valves and valve seats for internal combustion motors and is also used in razor blades, knife blades, hack saws, cold chisels, files, stamps, drills, springs, resistance wires, armor-piercing shells, erosion-resistant liners for large guns, and in the manufacture of specially tough armor plate.

Tungsten is also used in many nonferrous alloys. A copper-tungsten alloy has become popular as an electrode in the electric welding industry because it does not soften at red heat. The use of a hard facing on tools of soft steel has become increasingly important, and tungsten is found in nearly all such alloys. Stellite, one of the best known of this group, contains from 50 to 65 per cent

cobalt, 30 per cent chromium, and 4 to 15 per cent tungsten. It is used as a facing on tools subject to heavy abrasion and wear, such as drills and cutting tools.

The art of fabricating tungsten carbide into tools was developed in Germany during the nineteen-twenties, and although such tools or facings are still expensive, the ultimate saving in their use is great. Tungsten carbide wire-drawing dies last from 50 to 150 times as long as the best steel wire-drawing dies. In making a tool, a small amount of cobalt is mixed with powdered tungsten carbide, is pressed into shape, and is partly sintered at a moderately high temperature. In this condition the tool can be readily shaped, but allowance must be made for shrinkage of more than 10 per cent in the final sintering process to which it is then subjected. The product of the second heating is a dense metallic-appearing carbide that can be ground or modified in shape only by the use of diamond dust or diamond-pointed tools. Tungsten carbide cutting tools will last from 25 to 100 times as long between sharpenings as the best high-speed tungsten tool steels; in addition, the carbide tools can be used for cutting porcelain and other hard materials that high-speed steel would leave unscratched.

One of the best-known and most important uses of tungsten is in the electric light filament. Here its electrical resistance and extremely high melting point allow an extraordinary degree of efficiency in converting electric current into light. Although only 30 tons of tungsten is used for light filament annually in the United States, tungsten filaments have an efficiency so much greater than any known substitute that they earn several times their cost in a single hour of use. It is probable that the saving so effected is as great as that due to all the other tungsten used in industry.

Only a small amount of tungsten finds its way into the chemical industry; it is used in making flame-proof cloth, in weighting fabrics, and in preparing pigments for both paint and ceramics. Fluorescent cadmium tungstate is used in preparing X-ray screens.

Substitutes for Tungsten

Molybdenum can be substituted for a considerable proportion of the tungsten used in ordinary tungsten tool steel. The use of substitute metals, however, nearly always results in a less satisfactory alloy. A substitute that at first seems to be no substitute at all is tungsten carbide facings on tools. Although this hard facing contains much more tungsten than the tool steels, only the actual

cutting face need be made of the tungsten carbide, the remainder of the tool being ordinary stock. This substitution of a high-tungsten alloy for a small part of a large tungsten tool, greatly increasing the life of the tool, leads to a double saving of tungsten. Chromium, nickel, and molybdenum can be used as partial substitutes in armor-piercing shells. There is no satisfactory substitute for tungsten filaments in electric light, although the inefficient carbon filament could again be employed in an extreme emergency. Tungsten has been substituted for platinum in making contact points in various types of electrical apparatus. Recently, hard silver alloys have been tried successfully as a substitute for the tungsten and platinum contact points.

Technology

The chief ore minerals of tungsten are scheelite (calcium tungstate) and wolframite (iron-manganese tungstate). These minerals are chemical combinations of tungstic acid with calcium or iron and manganese. Such ores are sold in the market on the basis of the tungstic acid contained. Ores of standard grade contain 60 per cent tungstic acid (tungsten trioxide), and the prices are quoted in "units" of 20 pounds. Thus, a price of $20 per unit of 60 per cent tungstic trioxide means that ore containing 47.6 per cent tungsten is worth a dollar a pound.

The ore minerals are heavy and insoluble and are usually associated with quartz or garnet. Except for small deposits of unusually high grade, the ore is crushed and concentrated in "gravity mills" where the lighter silicate minerals are washed from the heavy scheelite and wolframite. The resulting concentrates may be used either to produce metallic tungsten or for the iron-tungsten alloy, ferrotungsten.

Metallic tungsten is prepared by a rather elaborate chemical process. The concentrates are mixed with sodium carbonate and finely ground before charging to a reverberatory furnace; here the material is heated to just below the fusion temperature in order to promote a chemical reaction between the tungsten and the soda, which converts it to a water-soluble sodium tungstate. This is leached from the residue, filtered, and finally precipitated as tungstic acid 99.53 per cent pure. The tungstic acid is heated and reduced in a stream of hydrogen in electric tube furnaces to form a metallic powder. The first step in producing ferrotungsten is to purify the concentrate by roasting and magnetic separation, unless high-grade

material is available. Ferrotungsten itself is made in an electric furnace where the roasted concentrates are mixed with carbon and flux and then fused in an electric arc. The charge is allowed to cool in the furnace and is later dug out to be remelted with an oxidizing flux for further purification.

Standard ferrotungsten should have not more than 3 per cent of carbon and should be from 75 to 80 per cent tungsten. The price of tungsten ore commonly ranges between $15 and $20 per unit of its tungsten trioxide equivalent, and the price of ferrotungsten is generally quoted at from $1.50 to $2.00 per pound of contained tungsten, about twice the value of tungsten in ore.

Geology

The primary ores of tungsten are found in a wide variety of geologic associations. Some tungsten is mined in igneous rocks, where it commonly occurs in the coarse-grained granite called pegmatite. Such ore bodies are small and pockety. The most important type of tungsten deposit is that found in limy rocks adjacent to bodies of granite or similar igneous rocks. Scheelite is the usual mineral in these contact metamorphic deposits. Both wolframite and scheelite are also found in quartz veins. Scheelite itself is difficult to distinguish from quartz in ordinary light, but it has the peculiar property of glowing or fluorescing when it is in ultraviolet light. This fact has led to the development of portable ultraviolet lamps and the anomalous circumstance that a prospector, with the aid of the invisible ultraviolet rays, has a better chance of seeing tungsten ore in the dark than in daylight.

All the tungsten minerals are resistant to weathering and tend to accumulate as residual deposits where the ores crop out at the surface. Such residual concentrations are known as "float" and are an important source of supply. Much of the ore that weathers out at the surface is washed into stream gravels where it accumulates as placer deposits. As tungsten minerals are relatively brittle and are soon broken up by stream action into an easily transported powder, placers are only found close to the outcrop area.

Important Sources of Tungsten Ore

China

Western China produces approximately two-thirds of the world's tungsten. The deposits are found near a belt of granite intrusions

of Mesozoic age in the provinces Kiangsi, Hunan, Yunnan, Kwangtung, and Kwangsi. Nearly all the ore shipped is wolframite, and 90 per cent of it comes from the southern part of Kiangsi, two hundred miles from Canton. The district is relatively inaccessible and little is known of the primary deposits. "Float" and placers furnish nearly all the material shipped. The low wages paid Chinese labor has enabled the producers to market their "wolfram" at about one-third the cost of producing ore in the United States. Nearly all the deposits are owned by Chinese capital, and no large organizations dominate the field.

In *Chosen* (Korea), wolframite and scheelite occur in quartz veins and as replacements in both quartzite and limestone. The major commercial deposits are placers derived from them, which furnish from 5 to 10 per cent of the world's output.

The Malay States, Siam, Indo-China, and India

Important placer deposits of wolframite have been worked in French Indo-China for many years, and tungsten is an important by-product of the mining of tin in the Malay States and Siam. Most of it is won by dredging. Wolframite is associated with tin near Tonkin also. Tin and tungsten veins of Hercynian age cut the granite and schist of the mountain ranges between Burma and Siam. Much of the ore is obtained from placer deposits, however.

The United States

The United States was the world's largest producer of tungsten before the discovery of the Chinese deposits during the first world war, and remained in second place from 1918 to 1942. Most of the production has come from Colorado, Nevada, and California, each state being successively our largest producer. In Colorado, an iron tungstate (ferberite) is intergrown with quartz in narrow "pockety" veins of Tertiary age which cut the pre-Cambrian granite of the Front Range about 10 miles west of Boulder.(10) Most of the tungsten in Nevada and California comes from replacement bodies of scheelite in limestone at the intrusive contacts of Mesozoic granite. Scheelite veins in the Atolia district, California, near the northern edge of the Mojave desert, were the chief source of domestic tungsten in the latter part of the first world war.(9) Contact deposits at Mill City, Nevada, became the leading source of tungsten during the nineteen-thirties. However, during the second world war, the great contact deposits near Bishop, California, be-

came the most productive in the United States. This district is near the western side of a large mass of Mesozoic granite which partly or wholly surrounds extensive irregular blocks of mineralized limestone containing from 0.5 to 1 per cent of tungsten trioxide.(8)

Bolivia

The principal tungsten mines of Bolivia are in the Department of La Paz, but some tungsten is mined in the Departments of Oruro and Cochabampa.(5; 11) Many of the mines have such low-grade ores that they can be worked only in times of unusually high prices. The ore is found in veins that cut across altered quartzite near the contact of intrusive granite, but in some places near the Bolsa Major mine, the veins parallel the bedding planes in the tilted sediments. In nearly all the mines copper is associated with the tungsten, and tin occurs in a few. Much of the ore mined averages about 2 per cent tungsten trioxide. The productive capacity is about equally divided between a few mines run by large companies and the many small properties belonging to independent operators.

Argentina

Tungsten is scattered through a wide belt along the eastern edge of the Andes, but the most important mines are in the Sierra de Cordoba and the Sierra San Luis, which form part of the Pampas Range. Paleozoic sediments have been metamorphosed to schist and gneiss by intrusive granites, and east-west tungsten veins are localized near the contact of the granite and the older rocks. The veins vary from a few inches to a few feet in width and contain wolframite and scheelite with a minor amount of iron, copper, zinc, bismuth, and molybdenum sulphides. Most of the mines are small and can be closed down or opened up in response to price fluctuations at little expense to the owners. The continued rise in output during the nineteen-thirties reflects an increasing number of operating properties rather than the discovery of any large new deposits.(5; 7) Figure 34 shows these and other tungsten districts.

Portugal

Portugal is the only important tungsten-producing nation in Europe. Most of the ore comes from Panasquiera in the province of Beira Baixa near Silvares and Biseu. Wolframite is found in veins associated with copper sulphide and in placer deposits near by. The

greater part of the production has been under the control of British companies.

Production and Consumption in the Industrial Countries *

The United States

Although the production of tungsten ore almost stopped for a time during the depression of 1930–1935, this country produced from 2,000 to 3,500 tons of concentrates a year through most of the decade preceding the second world war. This was about half the amount used. China supplied from one-third to two-thirds of the imports, and until the war interfered with our foreign trade, the rest of the imports were rather evenly distributed among Malaya, Argentina, Bolivia, Australia, Mexico, and Peru. The disruption of the Pacific and Atlantic supply lines during the second world war led us to turn to South America for an increasing proportion of our supply. Because of the greatly increased demands for tungsten steel during war, the United States took 9,995 tons of concentrates (60 per cent tungsten trioxide) in 1940, and her requirements more than doubled after her official entry into the conflict December 8, 1941.

Germany

Since no important tungsten deposits exist in the region under German control, Germany is wholly dependent on imports for her normal needs. During the war her consumption of tungsten probably ranged between 12,000 and 15,000 metric tons of 60 per cent tungsten trioxide. Much ore had been accumulated in stockpiles, and a considerable amount reached Germany by way of the Soviet Union prior to her invasion of that country; in addition, Spain sent a few hundred tons to the Reich each year.

France

France contains small deposits of tungsten, but her output has been negligible. Most of her supply has come from the Orient. French Indo-China supplied approximately 25 per cent of the 2,500 to 3,000 tons of concentrates required annually by the French steel industry.

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* The production of tungsten ore is summarized in Table XLIX.

The United Kingdom

The copper-tin-tungsten deposits of Cornwall were at one time the most important in the world. The gradual exhaustion of this district reduced the output of tungsten ore to only a few hundred metric tons annually during the nineteen-thirties. However, Great Britain was able to supply much of her consumption of 12,000 to 15,000 tons of concentrates from within the Empire. Burma supplied the greater part of the British requirements, and the rest came from the African colonies and from China.

The Soviet Union

Tungsten minerals have been found in many places in the Soviet Union, but the deposits discovered up to 1942 have been disappointing. The placer deposits of the Dzhida in the Far East were the chief domestic source of ore in 1940. Some ore was contributed by several other districts including Gumbika, the southern Urals, the Tuimsk-Minusinsk district of Siberia, and Belukha and Bukuka in the Transbaikal. A tungsten-molybdenum property in the heart of the Caucasus produces a small tonnage of both metals. From these and other districts the Soviet Union produced about 2,200 metric tons in 1937. The estimated reserves were sufficient to maintain this production for six years. So far as is known, the imports of tungsten are small and the Soviet Union is nearly self-sufficient in this important mineral, if the estimates of her engineers are not overoptimistic.

Japan

Japan's production of tungsten is negligible, but she obtained ample for her needs from China and Chosen (Korea) when Japanese troops marched into those countries.

Commercial and Political Control

The tungsten produced in China is under Chinese ownership, except for the region occupied by Japan. British capital dominates the tungsten production of Burma, Malaya, Portugal, Australia, and Africa. American capital controls the production in the United States and some of the production in Bolivia and Peru.

National Policy

The vital part played by tungsten in armament and other munitions of war, and in the high-speed steel that can hurry them out in an emergency, has led all industrial nations to make strenuous efforts to assure themselves of an adequate supply of tungsten during a possible emergency. Germany built up a stockpile, and Japan acquired a substantial amount of the Chinese ore. The United States subsidized exploration and operation of tungsten properties in the western states and actively encouraged the development of tungsten mines in various Latin American countries. Argentine tungsten was given the benefit of a Favored-Nations trade agreement in spite of the strong opposition of domestic producers. The government-owned Metals Reserve bought foreign ore for a government stockpile, and both production and sale of domestic ore were placed under strict federal control even before Japanese-American hostilities started. In the future, more adequate stockpiles of tungsten ore and other strategic minerals will probably be maintained by all the powerful industrial nations.

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CHAPTER 13

Molybdenum

Properties and Uses

METALLIC molybdenum melts at 2,550 degrees C. (4,622 degrees F.) and has a specific gravity of 10.2. Its electrical conductivity is a little less than one-third that of copper and its tensile strength is 260,000 pounds per square inch.

Molybdenum imparts to its alloys strength, toughness, and resistance to repeated shocks. These properties are retained at a moderately high temperature and make molybdenum a partial substitute for tungsten and chromium.

Molybdenum finds its principal use as an alloying element in iron and steel. The so-called low-molybdenum steels contain less than 1 per cent and are used extensively in the automotive industry and in the manufacture of agricultural implements, railway forgings, and bolts. The high molybdenum steels (containing more than 1 per cent of molybdenum) are much used for permanent magnets, rustless steels, dies, and high-speed tools.

The greater strength of molybdenum steels as compared with ordinary steel reduces weight materially. The railroad industry has made molybdenum steel standard for crank pins, piston rods, and crossheads, because of the resulting reduction in "track hammer." It is also used for firebox sheets, syphons, and similar parts because it retains its strength at elevated temperatures. The drilling and pumping equipment used in the oil industry is now commonly made of molybdenum steel. Although inferior to chrome steel for tensile strength at high temperatures, molybdenum steels can be used at many places in oil refineries where ordinary steel is unsatisfactory. Some molybdenum steels can be flame hardened and their resistance to wear can be greatly increased. Such steels are being used for pump plungers, guide blocks, heavy duty gears, and other types of machinery where resistance to wear is essential. Molybdenum steel is also used in certain types of armor-piercing shells and in armor plate itself.

A small amount of molybdenum added to cast iron increases the machineability and adds strength and toughness. This use is constantly increasing, especially in castings that are subjected to considerable pressure and wear. A small amount of molybdenum is also used in the chemical and ceramic industries.

The assurance of an adequate supply of molybdenum for many years to come has played an important part in the constantly increasing use that is made of this metal in the steel industry. The performance of molybdenum steels in most fields is so nearly equal to that of slightly better alloy steels that its substitution is inevitable when these other alloy metals are difficult to obtain.

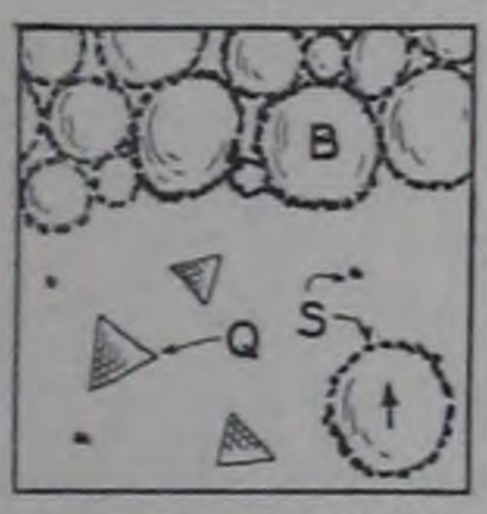
Technology

Although several molybdenum minerals are known, the only one of commercial importance is molybdenite, the molybdenum sulphide, which contains 60 per cent molybdenum. From it almost all the molybdenum in the world is obtained. Most ores have a very small percentage of molybdenite and a large amount of quartz. Fortunately the sulphide is readily concentrated by the flotation process. The ore is first crushed to a fine powder so as to free the flakes of molybdenite from quartz. The comminuted material is washed into flotation cells where oil, chemical reagents, and air are introduced while the liquid is agitated vigorously. (See Figure 33.) The chemical affinity of the various substances for each other is such that the air bubbles become surrounded with a film of oil while the molybdenum sulphide, which is more easily wetted by oil than by water, collects on these films. The quartz is more readily wetted by water than oil and shuns the oil film. Each little bubble of air acts as a tiny balloon to raise the oil film crowded with molybdenite particles up to the surface where they collect as a heavy froth rich in molybdenite. By this process it is possible to make a concentrate containing more than 95 per cent molybdenite, although the original ore carries less than 1 per cent.

High molybdenum steels are made from ferromolybdenum, but the low "molly" steels, as they are known to the trade, are made by adding calcium molybdite. After molybdenum is roasted to remove the sulphur, the resulting molybdenum oxide may be converted to ferromolybdenum by reducing it with carbon in the presence of iron in an electric furnace. This is the usual method. Metallic molybdenum can be made from molybdenite in the electric furnace by using coke to reduce the metal and lime and fluorspar to slag

off the sulphide. Molybdenum powder is obtained by heating the oxide in a current of hydrogen, a process identical with that used in making tungsten powder.

The price of molybdenum ore varies but little from 45 cents a pound of contained molybdenum sulphide, and the standard grade of ore carries 90 per cent. For many years ferromolybdenum was sold for 95 cents a pound.



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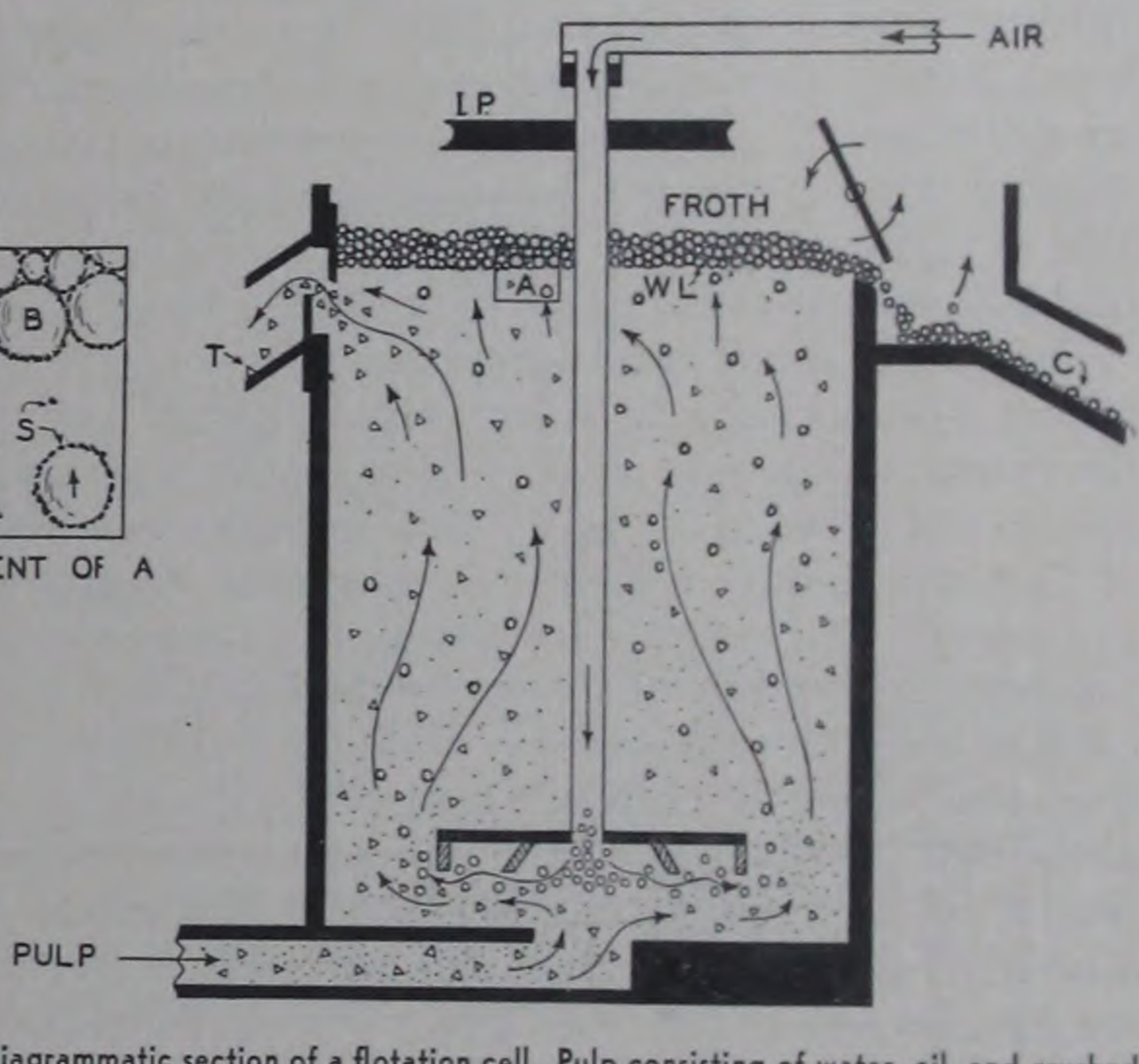

Fig. 33. Diagrammatic section of a flotation cell. Pulp consisting of water, oil, and crushed ore enters at the bottom and comes in contact with air bubbles, which become surrounded with a film of oil. The sulphide ore minerals, S, adhere to the oil film, are floated to the top and are removed with the froth. The barren quartz does not stick to the oil film but passes out at the overflow as tailings. IP, impeller pulley, T, tailings. WL, waterline. C, concentrates.

Geology

Molybdenum has a surprising range of geologic occurrence but is nearly everywhere associated with quartz. Molybdenite has been found as segregations in granite, as "pockety" deposits in dikes of pegmatite, in contact deposits in limestones adjacent to granite, and in quartz veins. A special and important class of this last group is the "stockworks," a large mass of shattered rock through which innumerable veinlets of quartz and molybdenite extend.

Important Sources of Molybdenum Ore

The United States

Climax, Colorado. Through most of the nineteen-thirties from 80 to 85 per cent of the world's molybdenum came from a stockworks deposit at Climax, Colorado, in the heart of the Rocky Mountains. Mining began during the first world war but was shut down in 1919 and was not resumed until 1924. From that time Climax has been a steady producer and has gradually increased the amount of ore milled until it is now the largest metal mine in Colorado. The capacity of its flotation mill increased from 2,000 tons of ore daily in 1930 to 12,000 tons daily in 1940, and its annual production of molybdenite since 1935 has ranged from 5,000 to 14,000 tons annually.

The geology of the molybdenum deposit is unique. The Climax district is broken along its western edge by a great fault that brings the Paleozoic sediments on the west in contact with pre-Cambrian granite and schist to the east. Both formations are cut by dikes of Tertiary igneous rock related to granite (quartz monzonite porphyry). The molybdenum deposit is a stockworks in the pre-Cambrian granite but formed during the Laramide revolution. It contains a central conical core in which the rocks have been largely converted to quartz. This core is about 800 feet in diameter at the surface but enlarges downward. Around it is an envelope of altered granite cut by innumerable closely spaced intersecting veinlets of quartz and molybdenite. The veins decrease in number away from the silicified core and the rock grades into unaltered granite. The envelope that contains the molybdenite is approximately 400 feet in thickness and completely surrounds the central core of silicified rock. Diamond drilling has indicated the presence of reserves sufficient to assure operation for many years.(1)

Questa, New Mexico. At Questa, New Mexico, granite intrudes pre-Cambrian metamorphic rocks. Many discontinuous quartz-molybdenite veins lie within the granite near the gently sloping intrusive contact and are subparallel to it. Each vein has only a small vertical range. Many of the veins have rich ore, but the known reserves are not large. This property is the chief source of molybdenum for the Molybdenum Corporation of America.(8)

By-product molybdenite. During the nineteen-thirties, some of the large copper companies discovered that it was possible to save the minute amount of molybdenite associated with the great de-

posits of disseminated copper known as "porphyry coppers" in the western United States and in Mexico. Because of the extremely large tonnage of copper ore mined annually, this by-product mineral has become the second largest source of molybdenum in the world. In 1940, 30 per cent of the molybdenum produced in the United States came as a by-product from the winning of copper ore; 66 per cent came from the Climax molybdenum deposit in Colorado; and nearly all the remaining 4 per cent can be credited to the Questa deposits.

Norway

Molybdenum has been produced at Fjotland in southern Norway for many years by the Knaben Molybdenum Mines Limited. The annual output of the country is almost identical with the output of this property, which is equivalent to 400–450 metric tons of molybdenum metal.(4) Prior to the German occupation of Norway, the Norwegian production was controlled by British capital.

The Soviet Union

Although a number of molybdenum deposits of low grade have been found in the Soviet Union, the first molybdenum smelter, completed in 1941, was built to treat molybdenite produced as a by-product of concentrating the copper ores of Kounrad, Kazakstan, north of Lake Balkhash. The copper ores at Kounrad are almost identical in their geology and mineralogy with the "porphyry copper" ores of the western United States.(2)

Morocco

Morocco has for many years produced annually the equivalent of 100 to 125 tons of molybdenum from contact metamorphic ores in limestone at Azegour, French Morocco.

Mexico

The by-product molybdenite obtained from copper ores in Mexico each year is the equivalent of about 1,000 tons of molybdenum metal.

Chile

The large copper deposits of Chile will probably yield an increasing amount of by-product molybdenite. The Braden Copper Com-

pany began to save molybdenite in their mill in 1939 when 800 to 900 tons of the sulphide were concentrated.(2; 8)

Peru

In recent years the quartz-molybdenite veins of the "Peru-Molybdeno" near Rikan in the Department of Junine have furnished some ore to foreign markets. Starting with 13 tons in 1936, the production increased to nearly 350 tons in 1939, but dropped perceptibly in 1940. The known reserves at the principal mine are more than 100,000 tons containing 0.8 per cent molybdenite, and several undeveloped molybdenum properties are also known in the area.(9)

Production and Consumption

The production of molybdenum in representative years is given in Table XL in the Appendix. All of Peru's production normally moves to Japan. (Figure 34 shows location of chief producers.)

TABLE XI

CONSUMPTION OF MOLYBDENUM PRODUCED IN THE UNITED STATES*
(in pounds of concentrates)

Country	*1939*	*1940*
United States (approx.)	21,139,700	53,578,200
Soviet Union	18,142,378	654,789
Japan	9,361,160	—
United Kingdom	7,556,560	3,985,961
France	2,960,543	5,299,380
Netherlands	2,734,211	11,200
Italy	1,004,440	1,650,650
Total Exports	43,554,310	12,677,794

* (7, p. 612).

Influence on National Policy

The pre-eminent position of the United States in the production of molybdenum has allowed this country to use her molybdenum export licenses as a lever in international diplomacy. The "moral embargo" placed upon the export of war materials to aggressor nations in the early stages of the second world war included molybdenum and forced the Axis nations to do without most of their normal supply of this important ferro-alloy element. Germany obtained some molybdenum from Norway, Morocco, and Greece, but Japan had no source after the supply from the United States and South America was cut off.

The comforting assurance of adequate future supplies that is given by the large reserves proved at Climax led the steel industry of the United States to adopt this metal where possible in preference to other alloy metals, even though the others were slightly more suitable for a given purpose. The Climax Molybdenum Company carried on research to develop new uses for the metal and made the patent processes covering the results cheaply available to its customers. If the present trend continues, molybdenum will become more extensively used in the steel industry than its greatest rival, tungsten. It must be remembered, however, that the reserves of molybdenite are very finite; the unhealthy boom-time demands of war require such an inordinate amount of alloy steel that within a comparatively short time sources conformably adequate for peacetime industry may become sufficiently depleted to cause concern.

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CHAPTER 14

Vanadium

Properties and Uses

NINETY-FIVE per cent of our vanadium is used for steel and iron. Vanadium unites with oxygen so readily that it is very difficult to produce the pure metal. It was formerly employed as a deoxidizing agent for special steels, as it serves even better than does manganese for this essential job. However, this use has been decreasing and it is now employed almost wholly in making special alloy steels. Vanadium steels are pre-eminent among those resisting fatigue and shock. Chrome steels that contain from 0.7 to 1.4 per cent chromium and from 0.1 to 0.25 per cent vanadium have a very high resistance to failure from fatigue and are employed for axels, springs, and whatever parts are subjected to repeated stresses. Manganese-vanadium steels are easily welded, have a high strength, and are readily worked. They are extensively employed for constructional steels and pressure vessels. Chrome-vanadium steels are popular in the automotive industry and are being used extensively for ordnance also.

Vanadium greatly inhibits grain growth in steel during reheating, and as both hardness and strength are related to grain size, this property makes it specially desirable for large forgings that require several heat treatments. One of the most recent advances in this field is the discovery of a vanadium-titanium-ferro alloy that makes a steel with a remarkably uniform grain size. Since this steel retains its grain size through many successive heats, its hardening capacity is greatly increased. When vanadium and molybdenum are used together, a steel can be made that has most of the characteristics of a tungsten steel. This combination is finding wide use for high-speed tool steels. In contrast, surprisingly enough, molybdenum and vanadium are also combined for making a special cast iron that has a high strength but is comparatively soft and easily machined.

The chemical industry uses a small amount of vanadium as a

catalyst in the manufacture of sulphuric acid and as a pigment in glass, ceramics, and paints.

Technology

Vanadium is contained in its ores either as the sulphide patronite or in the form of some of its oxygen compounds. To prepare vanadium for the steel industry the vanadium minerals of the ore are usually first converted to a simple oxide by roasting or some chemical process and the oxide is then reduced with carbon and iron in an electric furnace to form ferrovanadium containing 35 to 40 per cent vanadium. Some magnetic iron ores contain a small amount of vanadium; this is readily concentrated in the slag when the ore is smelted. The vanadiferous slag may be far richer than ore from commercial vanadium mines and can be treated by chemical processes similar to those used for the ores. The Anaconda Copper Mining Company in the United States has developed a process for recovering vanadium from sedimentary phosphate rock and expects to produce at least 50 tons of vanadium annually. Some vanadium is also obtained as a by-product from refining uranium ores with which vanadium is commonly associated.

Geology

Vanadium is widely but sparsely distributed in igneous rocks and sedimentary deposits. Some magmatic magnetite deposits in the eastern United States carry nearly 1 per cent of vanadium. It forms an appreciable part of some sedimentary iron ores, phosphate deposits, and petroleum. Soot from certain fuel oils is an important auxiliary source of vanadium; that from the Maricaibo oils of Venezuela contains from 35 to 40 per cent vanadium oxide. Vanadium minerals also occur in veins and replacement deposits formed by magmatic emanations. Vanadium, however, is the chief constituent in few such deposits; in most of them it is only a minor constituent found in the oxidized ore near the surface.

Important Sources of Vanadium Ore

Peru

The greatest vanadium mine in the world is in Peru at Minas Ragra and is owned by the Vanadium Corporation of America. The mine is at an elevation of 16,500 feet, 25 miles north of Ricran in the Department of Junin. From this mine came 55 per cent of the

entire output of the world prior to 1910—an amount equivalent to nearly 10,000,000 pounds of vanadium metal.

At the mine, Cretaceous limestones and shales are intruded by dikes of igneous rocks, and the deposit is next to a dike. Prior to 1932 when the mine was closed because of oppressive taxes, nearly all the ore mined was patronite; but this sulphide ore was nearly exhausted when mining halted. Since the property reopened in 1935, a red calcium vanidate which carries up to 50 per cent vanadium oxide has been the ore mineral. It occurs in pockets and small fissures in the Cretaceous shales. The deposit is a lens-shaped mass 30 feet wide and 350 feet long which slopes west at about 75 degrees. The ore reserves are known to be adequate for many years at the normal rate of extraction, equivalent to about 1,200 tons of vanadium per year.

The United States

The United States was the second largest producer of vanadium in the world when it entered the second world war. Nearly all its vanadium comes from western Colorado, but the vanadiferous shale of the Phosphoria formation, widespread in southwestern Wyoming, may become an important source in the future. Experimental work directed toward utilizing titanium-bearing iron ores that carry vanadium has encouraged the hope that titaniferous iron ores of New York, such as those near Lake Saranac, may became major sources of vanadium.

The United States Vanadium Company controls most of the production in Colorado, but a small amount is also in the hands of the Vanadium Corporation of America. Ore is mined in western Colorado and eastern Utah and shipped to the United States Vanadium mill at Uravan, 90 miles south-southwest of Grand Junction, Colorado, the nearest point on a railway. The mill is largely a chemical plant. The ore is crushed and mixed with salt obtained in Paradox Valley six miles away, and the two are roasted in a continually operating rotary kiln. The soluble sodium vanadate formed in this process is leached from the insoluble rock residue. Vanadium oxide is precipitated in the leach solutions, filtered, dried, and shipped east for conversion into ferrovanadate at the electrometallurgical plant of the Union Carbide Company, the chief owner of the United States Vanadium Company.

The ore for the Uravan mill is not found in any one large mine but is supplied by many small mines, the largest of which has had

a total production of about 100,000 tons, averaging 2 per cent of vanadium oxide (1 per cent of vanadium). Most of the mines yielded less than 10,000 tons during their lives. They are scattered over a wide area from the northern to the southern part of western Colorado and through the southern half of eastern Utah. However, most of them are concentrated in a narrow belt about 40 miles long running north and south through Uravan. The two vanadium companies own many of the mines but commonly lease them to independent operators and take ore both from these mines and from mines that are privately owned.

All the vanadium except in a few small deposits about ten miles north of Uravan comes from sandstones in the lower part of the Upper Cretaceous Morrison formation. The moderately thick section of shale above the sandstone weathers back and leaves the resistant underlying sandstone exposed as a prominent bench ideal for prospecting by means of shallow drill holes.

The ore consists chiefly of a vanadium mica and vanadium clay, but there are also some uranium vanadate (carnotite) and several rare vanadium minerals. The vanadium was introduced into the sandstone after its deposition, but the source of the ore is uncertain. The region is remote from Mesozoic or Tertiary igneous rocks, and there is no indication that the ore came in along fractures from below. In places the ore follows the bedding, but the best ore is found where closely spaced narrow bands of ore cut across the sandstone, or where vanadium minerals have replaced the woody materials of fossil trees. Curiously enough, most of the trees are oriented east-northeast near Uravan, the same direction as the long axis of the sandstone ore bodies here.*

Beautiful crystals of lead vanadate are found in the oxidized ores of many deposits in the southwest, and occasionally a little of this material is taken out. Probably the most notable of the mines producing vanadium of this sort is the Mammoth mine about fifty miles north of Tucson, Arizona.(5)

Africa

Vanadium is mined in South West Africa and in Northern Rhodesia. At the Broken Hill lead-zinc deposit in *Northern Rhodesia*, vanadium is a by-product of mining the oxidized part of a lead-zinc

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*The author is indebted to Mr. R. E. Fisher, who made a detailed study of the Uravan district, for much of the information on the geology of this area.

ore body. At these properties of the Rhodesian-Broken Hill Development Company Limited there are ore reserves of 2,500,000 tons of oxide containing 23.5 per cent zinc and 0.83 per cent vanadium oxide. Because of these large reserves of oxidized ore, Northern Rhodesia should be able to produce 350 to 400 tons of vanadium per year for many years to come.(4)

Vanadium is produced in *South West Africa* chiefly at Tsumeb, but some ore is found at several other places. At Tsumeb solution cavities in the late pre-Cambrian Dolomite formation are filled with sand and rubble that contain copper-lead vanadate minerals in sufficient quantity to make an excellent ore. The mines here have reached a depth of approximately 1,500 feet. Although the deposits are spotty, the production of South West Africa ranges between 500 and 600 tons of vanadium.(1; 3; 4)

Production and Consumption

The production of Peru and the United States is largely consumed within the United States, but in the late nineteen-thirties several hundred tons of Peruvian ore were shipped annually to Japan. Most of the vanadium produced in Africa was consumed in Germany and France until the beginning of the second world war when all the exports were directed to England. Figures for the principal sources of the world's production are given for representative years in Table L in the Appendix. See also Figure 34.

It is interesting to note that when excessive export taxes were levied by Peru in 1932, Minas Ragra ceased operations and did not again come into production until 1935. During this time, other deposits failed to supply the normal demand for vanadium; and the steel industry, unable to satisfy its needs in vanadium, turned to molybdenum as a substitute. The ability of molybdenum to produce alloy steels with properties comparable to those of vanadium, and the assurance of a continued supply of "molly," completely reversed the relative position of these two metals in the steel industry. Prior to 1930 the production of vanadium was commonly two to three times that of molybdenum. In the next few years the production of molybdenum surpassed that previously attained by vanadium, and since that time the production ratio of the two metals has become increasingly unfavorable to vanadium. It should be stressed that this decrease in the use of vanadium does not reflect the superiority of molybdenum steels so much as it does the desire of the industry for a dependable source of supply.

Commercial Control and National Policy

American capital dominates the vanadium industry. The vanadium ores of the United States are marketed by the United States Vanadium Company and the Vanadium Corporation of America. The latter concern controls the Peruvian output and owns half the stock of the South West Africa Company, Ltd., which owns the Abenab deposit. German capital owned the producing properties at Tsumeb, but British capital controlled the remaining production in South West Africa and in Rhodesia. The by-product vanadium from vanadiferous iron ore, which promises to play such an important part in the future, is recovered from smelter slag. Commercial control of this source will be in the hands of those iron and steel companies that have access to vanadium-bearing iron ore. The Bethlehem Steel Company was the first in the United States to develop such ore and to separate vanadium as a by-product during the smelting process. In 1942 it was probable that at least 80 per cent of the world's vanadium output was under American control. The dearth of ferro-alloy metals in the Axis-dominated countries of Europe led Germany and Italy to employ every means of getting by-product vanadium. So successful were they that Italy was self-sufficient in 1940 and Germany was probably able to obtain more than her normal needs of this vital metal. Germany obtained enough vanadium from iron ore blast furnace slags alone to make her virtually independent of imports.(3) Italy obtained a substantial amount as a by-product in reducing bauxite, the sedimentary aluminum ore, and from the soot of Italian ships and industrial plants using naphtha as a fuel.(4) It is clear that the governments of industrial nations will strongly encourage all efforts to salvage vanadium from such sources in the future.

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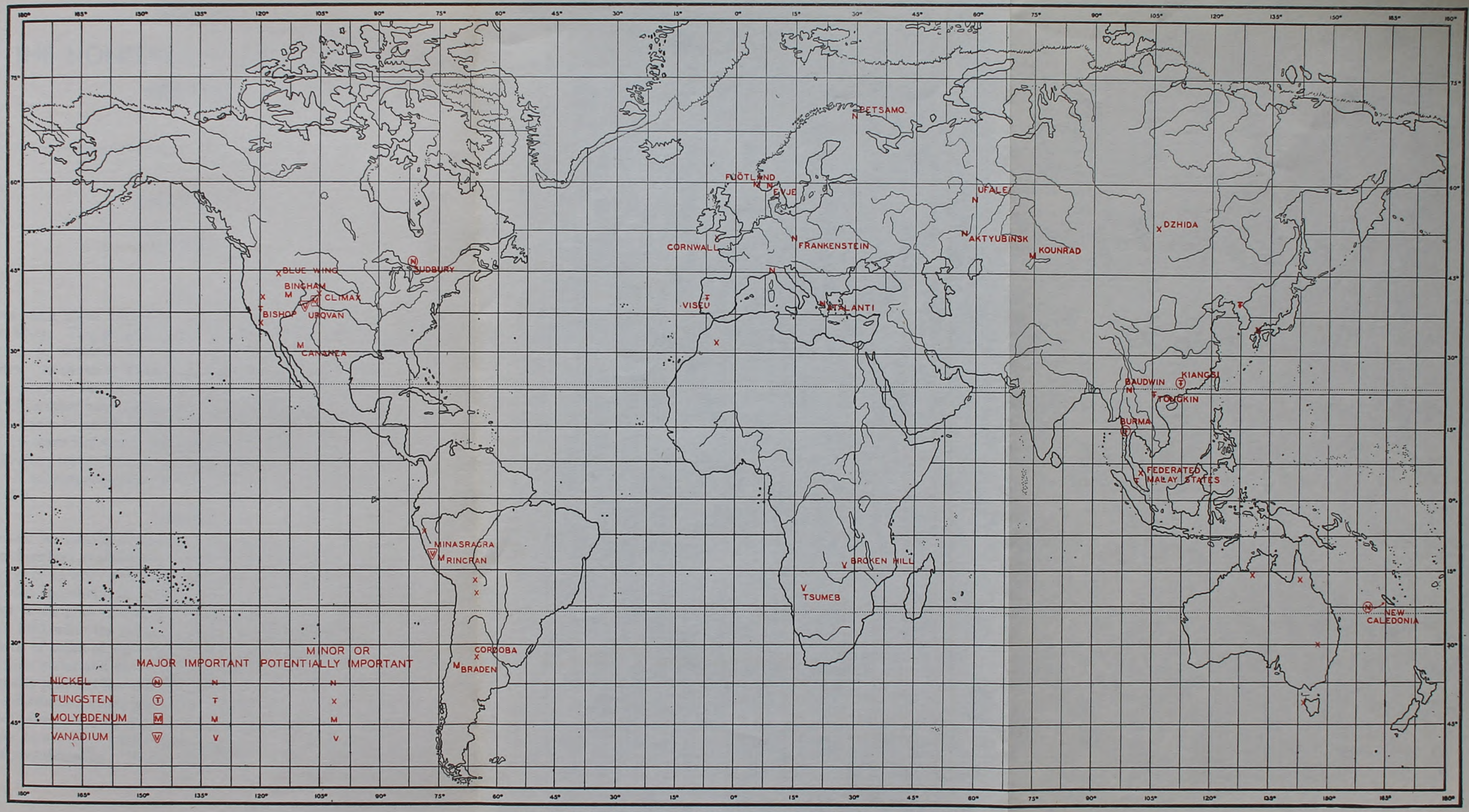

Fig. 34. Distribution of nickel, tungsten, molybdenum, and vanadium throughout the world.

Part IV

THE NONFERROUS INDUSTRIAL METALS

CHAPTER 15

Copper

Uses

COPPER has a higher electrical conductivity than any other metal except silver. This property, together with its tensile strength and resistance to corrosion, has made it pre-eminent in the electrical industry. As shown in Table XII, more than one-third of the copper produced in the United States goes into electrical uses. For many of its other uses copper is either combined with tin in bronze or with zinc in brass, alloys that average more than 80 per cent copper. As copper is of special value in the manufacture of ammunition and the many copper, bronze, and brass fittings of other munitions of war, it is not surprising that the demand skyrockets during periods of conflict.

Substitutes

Because our industrial world is dependent upon electricity, copper has long been regarded as a vital necessity to industrial nations, second only to iron, coal, and petroleum. However, it has been found that aluminum can replace copper satisfactorily for many of its uses, if the price of the two metals is the same. In the boom year of 1929, when the price of copper exceeded that of aluminum, hundreds of miles of electrical transmission cables were made of the lighter metal and put to work in the United States. Copper is normally priced at less than two-thirds the cost of aluminum, and such substitution would generally be uneconomic. Zinc also can be used to replace copper in some of its important uses where resistance to corrosion rather than conductivity or strength is the primary consideration. New methods of processing steel have made

it possible to use pressed steel for jobs previously requiring copper. The successful manufacture of steel shell cases in 1942 released millions of pounds of copper annually for other uses.

TABLE XII

ESTIMATED USE OF COPPER IN THE UNITED STATES, 1936–1940, IN SHORT TONS (11, p. 97)

Use	*1936*	*1937*	*1938*	*1939*	*1940*
Electrical manufactures [1]	164,000	212,000	150,000	185,000	247,000
Telephones and telegraphs	26,000	40,000	30,000	39,000	49,000
Light and power lines [2]	72,000	83,000	62,000	67,000	74,000
Wire cloth	6,500	6,800	6,000	8,000	9,200
Other rod and wire [3]	90,000	102,000	60,000	95,000	120,000
Ammunition	11,900	14,100	12,500	14,500	26,000
Automobiles [4]	108,000	112,000	55,000	85,000	103,000
Buildings [5]	71,000	70,500	67,500	89,000	102,000
Castings [6]	39,000	40,000	31,000	33,000	35,000
Clocks and watches	3,400	4,000	3,000	4,000	4,400
Copper-bearing steel	3,900	4,600	2,600	4,200	4,700
Radiators, heating	2,000	2,100	2,000	3,600	2,900
Radio receiving sets	24,000	23,100	21,000	27,000	32,000
Railway equipment [7]	4,000	7,100	1,700	2,700	5,700
Refrigerators [8]	15,000	13,500	6,700	10,000	10,500
Shipbuilding [8]	5,000	6,400	6,000	8,500	8,700
Air conditioning [8 9]	6,400	7,200	6,000	6,000	6,000
Other uses [10]	65,300	66,600	46,200	67,600	81,500
Manufactures for export	31,600	45,000	38,800	51,900	148,400
	749,000	860,000	608,000	801,000	1,070,000

1 Generators, motors, electric locomotives, switchboards, light bulbs, etc.
2 Transmission and distribution wire and bus bars, accounting only for the public utility companies.
3 Includes industrial wire and cable, wire in buildings, railway cars and ships, radio broadcasting, railway and municipal signaling, railway electrification, trolley wire, rod and wire for governmental projects, blasting wire, flexible cord and sundries.
4 Does not include starter, generator, and ignition equipment.
5 Excludes electrical work.
6 Bearings, bushings, lubricators, valves, and fittings.
7 Includes air conditioning.
8 Excludes electrical equipment.
9 Other than railway.
10 Includes condenser tubes, oil burner tubing, welding rod, screw machine products, nickel silver and phosphor bronze products, rivets and burrs, toilet pins, eyelets and grommets, electrotyping and engraving sheet, spark plugs, inner tube valve stems, jar tops and rough boxes, flashlight tubes, kerosene lamps, kitchen utensils, kitchen range boilers, linotype matrices, safety razors, blasting caps, asbestos textiles, water meters, thermostats, soldering coppers, yacht fittings, coinage, washing machines, household water heaters, fire extinguishers, pumps, airplanes, engines, and sundry machinery, etc., all reckoned in terms of copper content.

Technology and Economics

Most of the world's copper comes from three types of ore: 1) ore containing metallic copper; 2) ore containing copper sulphides; 3) oxidized ore in which the copper is present in simple or complex oxygen compounds.

The treatment of ores containing metallic copper is relatively simple. The ore is hammered under a battery of heavy steel

stamps, and as the light rock is broken loose it is washed away from the copper. The metal is then smelted, purified, and placed on the market.

Sulphide ores are crushed and concentrated by the flotation process (see page 250, *Molybdenum*). The copper sulphide concentrate is partly roasted to reduce the sulphur content and is then converted to matte in either a blast furnace or a reverberatory furnace, depending on the coarseness of the ore. In this operation, most of the iron associated with the copper is slagged off by the use of flux. The molten mass is then placed in a converter and "blown" in the presence of a small amount of silica flux. The air oxidizes the sulphur still present in the mass, and the silica slags off any iron that had entered the copper matte. The product of the converter is known as blister copper, because of the metallic bubbles or blisters that form when it is poured. The blister copper is ordinarily refined by electrolysis, unless the presence of silver and gold necessitates the taking of an intermediate step to recover these precious metals.

The electrolytic purification of copper is a rather touchy chemical process, and the solutions would soon become foul if the current were passed through blister copper anodes. The blister copper is first melted, aereated, and fluxed to eliminate most of the impurities, and then coal or coke is added to reduce the oxide formed in this process. At this stage green wood is added, and its moisture causes ebulition and stirs the whole mass while the carbon completely reduces the oxide present. This procedure is known as poling. The poled copper is pressed into anodes about 2 inches thick, 3.5 feet high, and 2.5 feet wide. The anodes, alternating with thin sheets of pure copper known as cathodes, are placed in copper sulphate solution. An electric current passes through the solution, dissolving copper from the positive anode and depositing it on the negative cathode as an almost chemically pure precipitate. Each ton of copper deposited consumes about 2,590 kilowatt hours of electricity.(5)

It is a testimony to the amazing efficiency of modern industry that copper can be mined from ores containing less than 1 per cent of the metal and taken through all the steps indicated above and a profit still be realized when the price of the metal on the market is as little as 8 cents a pound. However, such a price allows only our lowest-cost copper producers to operate profitably. Commonly the price of copper ranges between 10 and 14 cents per pound.

Oxidized ores may be smelted in the blast furnace or the reverberatory furnace with the direct production of metallic copper. If the oxidized ores are water soluble, as many are, it is cheaper to leach the oxidized ores and precipitate the copper from the leach solution by introducing metallic iron. Usually enough soluble copper is present in sulphide ores to make it worth while to treat the discharge solutions from flotation plants in this manner.

In addition to the copper derived from ores, a large amount of secondary copper comes on the market each year in the form of scrap. The United States consumed a little more than 1,000,000 tons of copper in 1940; of this, more than 530,000 tons were acquired from secondary copper.(11) Approximately 334,000 tons was so-called market scrap obtained from obsolescent articles and 198,000 tons was home scrap, the trimmings and waste produced in the manufacture of new articles. As most of the copper used by industry is employed either because of its electrical properties or its resistance to corrosion, most of it can ultimately be recovered and reused. Thus, in all civilized countries, large reservoirs of potential copper stock are continually being built up. During the second world war such copper was pressed into service by the Axis nations who are notably deficient in this metal. The Japanese systematically looted Manchuria, China, and the other countries which they invaded, exporting to Japan thousands of tons of bronze statuary and other articles containing copper.

Geology

Some deposits of native copper have contributed substantially to the world's production. These deposits are all localized in a small part of northern Michigan. Native copper is found in small quantities in many places, however, and everywhere is either associated with mafic lavas (basalts or trap rocks) or with oxidized copper minerals in the weathered zone of sulphide deposits. Copper sulphides and copper-iron sulphides make up the primary ore of nearly all copper deposits. When the sulphides are exposed at the surface, they readily combine with the oxygen of the air to form oxides and sulphates. Usually in this process sulphuric acid or ferric sulphate is formed, and iron sulphate is an active solvent for copper minerals in an acid solution. When these solutions descend to the water table, the copper is reprecipitated in the form of a sulphide, giving rise to a zone of secondary enrichment where the ore is much

richer in copper than either above or below. In arid climates this zone may be lacking and the copper may occur in oxidized compounds for a considerable depth below the outcrop.

Copper sulphide ore is found in primary deposits representing nearly all the types that are genetically related to igenous rock. It is associated with nickel in magmatic segregations. (See page 235.)

Forty years ago most of our copper was mined from contact metamorphic deposits and from veins. During recent years most of it has come from large, low-grade disseminated deposits of two types. In the so-called "porphyry coppers" the ore minerals are disseminated through the highly fractured altered top of an igneous intrusion known as porphyry. In copper-bearing sediments, such as are found in Africa and a few other localities, copper minerals have been introduced into the parent sediments and have been precipitated at the expense of a calcareous cement. The world's supply of copper in the future will probably come in increasing proportion from disseminated deposits of these two types.

Geology of Some Major Districts

The United States

The *Butte* copper district of Montana has produced more copper than has any other single district in the world; in addition it has produced large quantities of zinc, silver, and gold. It has yielded metals to the value of more than 2,000,000,000 dollars since copper was first mined here in 1868. The ores contain from 4 to 5 per cent of copper in various sulphides. The copper veins are concentrated in an east-west belt that is about two miles long and a mile wide, near the western edge of a great granite mass that was intruded during the Larimide revolution. The granite is cut by dikes of slightly later age, and both are broken by a complex system of faults. From the deeper and hotter part of the granite intrusion, mineralizing solutions rose through some of these fissures and deposited in them copper, gold, silver, and zinc minerals to form the rich persistent veins for which Butte is famous. Some of them have been followed to a depth of four thousand feet. Outward from the central area of rich copper lodes the veins contain less and less copper but more zinc, lead, silver, and manganese. The water from millions of storms has gradually leached the copper from the outcrops of Butte veins, and there was little at the

surface to tell the gold-placering pioneers who discovered the district that copper ore lay some two or three hundred feet below the surface.(4)

The *porphyry coppers* of Arizona, Nevada, and Utah have for many years supplied most of the copper smelted in the United States. These distinctive deposits are in granite porphyry intrusions, parts of which have been impregnated by copper minerals. The most productive deposits include Bingham, Utah; Miami, Arizona; Central, New Mexico; Ely, Nevada; Bisbee, Ajo, Ray, and the Copper Mountain or Morenci district, Arizona. The yearly production normally ranges from 15,000 tons of copper for the smaller districts to 200,000 tons for Bingham, Utah. Although differing in detail, these deposits all belong to the same type and have many things in common. The Bingham district, which is described below, may be taken as a typical example of the porphyry coppers.

The *Bingham* district is 20 miles southwest of Salt Lake City, Utah. It is in a region of gently folded thick Upper Carboniferous quartzites that contain many limestone layers. Irregular bodies of granite intruded the folded and faulted Paleozoic rocks during the Larimide revolution, and extensive contact metamorphic deposits formed in the roof adjacent to the porphyritic igneous rocks where favorable conditions were present. These contact deposits yielded a substantial production of lead, zinc, silver, and gold before methods were found of working the low-grade but enormous bodies of disseminated copper ore in one of the porphyries. The copper ore is in the upper part of the Bingham intrusion under an oval area about 6,000 feet long and 4,000 feet wide. Diamond drilling has proved that sulphides extend to a depth of about 3,000 feet, but only part of this depth contains commercial ore. The ground near the surface was oxidized and leached to a depth of 20 to 150 feet, and immediately below this barren zone good copper ore was found. Although the grade of the ore diminishes downward, commercial ore extends to a depth of about 2,000 feet. The average grade is a little more than 1 per cent copper, and the lower limit of commercial ore is placed at 0.6 per cent copper.(2)

Ore is mined by open-pit methods. What was a mountain of ore is being transformed into a bowl-shaped pit which will be 8,000 feet long, 6,000 feet wide, and 2,500 feet deep when completed and will necessitate the removal of 580,000,000,000 tons of rock (see Figure 35).

Hundreds of thousands of tons of ore are broken at a time by

a series of drill holes loaded with dynamite. This ore is then picked up by large mechanical shovels, loaded into cars, and moved to a flotation mill where it is crushed and concentrated. More than 80,000 tons of ore were treated daily during December, 1940, to produce 42,000,000 pounds of copper. The cost of producing a pound of metallic copper from this property ranges from a little less than 6 cents to about 7 cents. In addition to the copper, a substantial

Spence Air Photos.

Fig. 35. Open-pit mine of Utah Copper Co., Bingham, Utah, is the largest open-pit copper mine in the world. The picture can be scaled by the standard-guage trains on the third, fifth, and seventh benches on the far side of the pit.

amount of molybdenite is recovered as a by-product of the milling operation. This "porphyry copper," the largest single producer of copper in the world in 1940, is the property of the Utah Copper Company, a subsidiary of the Kennecott Copper Corporation owned by United States capital.

The famous copper mines of western *Michigan* lie in the Keewenaw Peninsula, which extends northeast into Lake Superior for 60 miles. Copper is found through a distance of more than 100 miles, but nearly all of the commercial ore is confined to a northeast trending belt about 26 miles long. The district has the second largest total production of any district in the world; between 1845

and 1930 it produced 8,403,640,000 pounds of copper and paid $328,603,052 in dividends.(3)

In late pre-Cambrian times mafic lava, or trap rock, was extruded intermittently from great fissures where Lake Superior now lies, and sheets of molten rock spread over the country for great distances. Sand and gravels accumulated on some of the flows, but many of them were piled on top of earlier lavas in such rapid succession that no sedimentary rocks accumulated. The steam dissolved in the magma at depth freed itself when the lava was extruded, causing a vesicular stony froth to form at the top of the flow. This made a porous permeable layer through which solutions could easily travel. The lavas and interbedded sand and gravel were tilted steeply to the northeast and broken by minor faults just before the Paleozoic era commenced. Mineralizing solutions rich in copper flowed upward through the tilted partly lithified gravel (conglomerate) and the porous tops of the lava sheets. These solutions deposited metallic copper as they gradually cooled during their ascent and formed the great lodes for which the district is world-famous. Some of the mines have followed these lodes for a slope distance of nearly two miles. At this depth the cost of mining is so great that the companies find it difficult to compete with the low-cost copper mined in the Southwest and abroad. However, at some places in this district, there is reason to believe that the copper continues to a slope depth of as much as twenty thousand feet below the outcrop.

In addition to the copper found in the conglomerates and the "amygdaloids," as the porous lava tops are known in this district, a small amount of rich copper ore was found in nearly vertical veins, but this ore has long since been mined out. Although the production of copper from Michigan was still of considerable magnitude in 1941, more than two-thirds of it was obtained from reworking the "stamp sands," the waste of early milling operations. Most of the mines of the Michigan copper country have been properly classed as marginal producers during the nineteen-thirties.

Chile

Chile is second only to the United States as a source of copper. Most of this copper comes from three deposits: Chuquicamata and Potrerillos, both porphyry coppers, and Braden, a disseminated copper deposit surrounding an ancient volcano. All of these deposits are related to igneous rocks of varying composition intruded during the Larimide revolution.

The *Chuquicamata mine* of the Chile Copper Company is probably the world's largest copper deposit and has over a billion tons of known ore reserves averaging about 2 per cent copper. The mine is 90 miles east of the coast, and 147 miles northeast of the port of Antofagasta, and lies at an elevation of a little more than 10,000 feet. The ore is in a much fractured intrusion (granodiorite) that is dominated by strong north or northeasterly fissure zones along which the ore is much richer than elsewhere. The outcrop of the ore body is pear-shaped and is two miles long with a maximum width of 3,600 feet. Ore has been proved to a vertical depth of 1,500 to 1,900 feet. The upper part of the deposit has been leached of copper to a maximum depth of about 500 feet. Under the leached capping is a rich blanket of oxide ore whose thickness is erratic and which gives way to sulphide ore in depth. The oxide ore averages 1.65 per cent copper, 90 per cent of which is soluble. The sulphide has an average of 2.25 per cent copper and is insoluble. Chuquicamata produces about 225,000 tons of copper annually and can maintain this rate of production for many decades. The story of its development in the deserts of northern Chile is well told by Parsons.(12; 13; 14)

Rhodesia and the Belgian Congo

In central Africa a great series of pre-Cambrian sediments crop out in Southern Rhodesia and the central part of the Belgian Congo in a long, curving, easterly trending belt. In both countries great deposits of copper ore are found disseminated in these ancient strata. In *Northern Rhodesia* the copper belt is a strip of country about seventy miles long that parallels the boundary with the Belgian Congo. The ore deposits are found in one or more beds of limy shale that carry disseminations of copper-iron sulphides below a zone of oxidized copper minerals. However, sulphide comprises most of the ore. The deposits extend over remarkably long horizontal distances and also persist to great depth. Since the ore is found at a definite stratigraphic horizon, the beds are easily prospected, once the geology has been mapped.(1)

The deposits of the *Belgian Congo* are found in the same series of rocks, but the copper replaces a dolomitic limestone instead of a limy shale. The ore-bearing beds of the Katanga copper belt have been slightly metamorphosed and are thrown into a series of open folds that trend north-west in the eastern part of the copper belt and east-west in the western part. Large masses of granite were

intruded during the folding and in places granite of still younger age is present.(7)

Rhodesia has three large mines: the Roan Antelope, the Mufulira, and the Rhokana. In 1940 these three were responsible for a production of more than 365,000 tons of copper. The copper of the Belgian Congo is in the hands of the Union Minere du Haut Katanga, controlled by the Belgian Government.

Production and Consumption

The world production of copper increased from about 250,000 tons in 1885 to 2,500,000 tons in 1940. The largest consumers are, of course, the leading industrial nations of the world, but only two of them, the United States and the Soviet Union, produce approximately what they consume in normal times. Statistics for the production and consumption of the leading countries of the world are given in the accompanying table; additional figures for production during representative years will be found in Tables XXVIII and XXIX in the Appendix.

TABLE XIII

PRODUCTION AND CONSUMPTION OF COPPER IN METRIC TONS IN THE IMPORTANT PRODUCING AND CONSUMING COUNTRIES*

	1936		*1939*		*1940*	
Country	*Cons.*	*Prod.*	*Cons.*	*Prod.*	*Cons.*	*Prod.*
Belgian Congo		95,667		121,498		156,000
Canada	45,800	191,260	(1)	281,465	(1)	317,000
Chile		256,208		339,173		352,439
Czechoslovakia	28,900		(2)		(2)	
France	113,000	1,000	120,000	1,000	140,000	(1)
Germany	185,000	29,800	400,000	30,000	380,000	(1)
Great Britain	258,500		290,000		380,000	
Italy	83,700		75,000		75,000	
Japan	126,900	73,807	217,000	77,000	235,000	(1)
Yugoslavia	2,800	39,124	(1)	41,658	(1)	(1)
Mexico		32,623		48,798		37,602
Peru		33,352		35,400		37,686
Rhodesia		173,478		216,004		265,000
Soviet Union	128,000	83,000	175,000	107,000	185,000	(1)
Sweden	43,800	7,606	68,000	10,500	40,000	(1)
United States	733,900	557,902	730,000	666,783	950,000	796,582
World	1,894,500	1,676,974	2,284,000	2,161,522	2,608,000	(1)

* (10, p. 133–134; 11, p. 107.)

1. Data unavailable.
2. German consumption for 1939 includes Czechoslovakia and Austria; for 1940 includes Poland also.

The United States

Normally the United States consumes from half to three-quarters of a million tons of copper each year, but during periods of high industrial activity its requirements are about a million and a quarter tons. Although our mine production was increased to more than 797,000 metric tons with difficulty during 1940, reserve stocks and imported ore, largely from Canada, Cuba, Newfoundland and South America raised our smelter production to 922,000 tons. Imports of copper (metal) totaled nearly 500,000 tons, but our exports fell short of this figure by only 70,000 tons. The imports of copper came chiefly from Chile (205,000 tons) but also in substantial quantity from the Belgian Congo (61,000 tons) and Canada (52,000 tons). The rest of the imports were from several other countries. (10; 11)

Chile

For many years Chile has been the second largest producer of copper in the world, and almost her entire output of about 350,000 tons is exported. Her copper reserves are so large that we may expect Chile to continue as the second or third largest producer of copper for decades to come. Ninety per cent of her production is under the control of American companies, the bulk of it coming from subsidiaries of the Anaconda Copper Company and of the Kennecott Copper Company. The United States is Chile's best customer and takes more than twice as much as does Great Britain, the second-best customer. Sweden, France, Belgium, and Italy all normally import substantial quantities of copper from Chile, but their imports fall far below those of Great Britain. During the second world war the United States absorbed virtually all of Chile's production.(14)

Rhodesia

Many believe that Rhodesia contains the largest copper reserves in the world. Certainly its reserves are comparable to those of the United States and Chile. It would be an easy matter to increase substantially the production of Rhodesian copper, and for a time there was danger of a price war between the British-controlled producers in Rhodesia and the American companies who had for many years dominated world markets. The proof that copper could be produced in large quantities from a few American properties and

from some of the South American mines as cheaply as it could in Africa, and the knowledge that this cheap copper would be used with devastating effect in any trade war, were the restraining influences that led African producers to be content with a moderate share of the world's copper market. Most of the African copper normally moves to Europe, but the United States also takes a small amount. The participation of American capital in Rhodesian mining was small for many years, equivalent to control of only about 12 per cent of the reserves. During the years just preceding the second world war, however, the American-controlled American Metals Company began investing heavily in African copper. By 1942, British and American control probably approached parity.

Belgian Congo

The Belgian Congo, formerly the fourth largest copper producer in the world, is now in sixth place. Nearly all the ore produced and smelted in the Belgian Congo is under the control of the Belgian Crown. The requirements of Belgium are, of course, filled entirely by imports from the Belgian Congo. A substantial amount also is exported to other European countries.

Canada

Canada normally produces slightly more copper than Rhodesia, but in 1940, when every effort was made to obtain maximum production, her output was 317,000 metric tons as against nearly 375,000 metric tons for Rhodesia during the same year. As more than half of the copper comes from the nickel-copper ore of Sudbury, her copper production is closely tied to the output of nickel. The remainder of the copper comes chiefly from Quebec and British Columbia. The Noranda copper-gold deposit furnishes about two-thirds of the copper produced in Quebec, and most of the copper in British Columbia comes from a property at High Sound, owned by the Britannia Mining and Smelting Company, and from the Copper Mountain mine near Allenby, owned by the Granby Consolidated Mining, Smelting, and Power Company. A substantial amount of copper is also produced at the Flin Flon mine in northern Manitoba close to the Saskatchewan border. Canada uses some copper in her industry but exports the larger part of her output to the British Empire and the United States. However, Germany and Japan are also good customers during peace time.

The Soviet Union

The Soviet Union stood sixth on the list of the world's producers in 1940 and is likely to remain in this position for some time. Her resources seem fairly well known, and although much larger than those of Japan, which is her closest rival, they are far less than those of the Belgian Congo, the fifth largest producer. Much trouble has plagued the Soviet copper industry for years, but ultimately the nation may be able to fill most of its copper requirements from domestic ore. The Ural Mountains formerly contained excellent mines, but several of them were nearly ruined by sabotage during the early nineteen-thirties.(6) Most of the important deposits lie east of the Urals in Kazakstan and much of the Soviet Union's present production probably can be credited to the porphyry copper deposits at Kounrad near Lake Balkash, where reserves of many million tons of copper have been proved by drilling.(8)

Japan

Japan is more nearly able to satisfy her needs in copper than in most other metals required by an industrial nation. A production of slightly more than 100,000 tons seems to be close to the upper limit, however, and Japan imported substantial amounts of copper from Chile, the United States, Canada, and Africa before the second world war.

Political and Commercial Control

The production of copper in the United States, the greatest producer in the world, is almost entirely in the hands of domestic capital. Ninety-two per cent of the copper of the second largest producer, Chile, is in the hands of three American companies, two of which, the Andes Copper Company and the Chile Copper Company, are subsidiaries of Anaconda Copper; the third, the Braden Company, is a subsidiary of the Kennecott Copper Company. Nearly all of the copper produced in Peru and Bolivia also is controlled by American interests, but French capital formerly dominated the comparatively small production credited to Bolivia. More than half the copper produced in Canada is also controlled by United States financial interests and the remainder is almost equally divided between Canadian and British interests. Two-thirds of Mexican production is in the hands of United States

interests, about one-sixth belonging to British companies and the other sixth to French companies.

Outside the western hemisphere the British held a dominant position, during the nineteen-thirties, due chiefly to their control of Rhodesian copper. In 1939 British capital controlled more than half the copper produced in Spain and a substantial part of both the actual and potential copper produced in Finland. The entire output of the Belgian Congo is, of course, in the hands of Belgian capital. Swedes control both the copper of Sweden and most of that in Norway. In 1939 French capital controlled the output of Yugoslavia and also participated in the copper output of Norway, Bolivia, and Mexico. The entire output of Japan is in the hands of Japanese nationals.

From the preceding summary it is obvious that the financial interests of the United States dominate the copper production of the world, and that Britain and her colonials control most of the sources of copper that American capital has been unable to acquire.

National Policy

The high-cost producers of the United States have long clamored for a protective tariff on copper in spite of the fact that we produced a surplus which had to be exported to other countries. The tariff was strongly opposed by financial interests that owned large amounts of low-cost foreign copper. However, the government has had an import duty of four cents per pound on copper for some time, although it allows copper ore and concentrates to enter for smelting and refining if they are then exported. Certain favored nations, such as Cuba and the Philippines, have been allowed to sell their copper to us without an import duty. The dominant position held by British capital throughout the nineteenth century was relinquished to American producers only after a bitter financial battle. With the discovery of Rhodesian copper, the old feud was renewed and British investment in African copper was regarded as not only profitable but a patriotic move designed to break the tight grip on world trade and prices exercised by American copper producers throughout the nineteen-twenties. The tardy realization that the American-controlled low-cost copper of Chile gave their adversary a "balance of power" prevented the Rhodesian copper producers from attempting entirely to displace American copper from foreign markets.

In the decade preceding the second world war, French and Ger-

mans competed for European copper deposits. The French won when they got control of the best copper deposits in southern Europe, the Yugoslavian deposits at Bor, about seventeen miles north of Zajechar. The meager production of Germany led to German investments in South Africa and to efforts to obtain control of copper producers in southern Europe and Finland. Germany is, of course, the natural market for copper produced in Fennoscandia. Prior to September, 1939, Germany obtained large stocks of copper from Rhodesia and the Belgian Congo in preparation for the subsequent loss of these sources. British exporters worked feverishly the night of September third till the last permitted minute to clear the cargoes of copper bought by Germany for the war they knew would start the next day. The copper mines of Yugoslavia, Finland, and Norway were important contributing incentives to the German conquest or domination of these countries.

Germany's industries suffered greatly during the first world war because of her deficiency in copper. Since aluminum can be substituted for copper in large measure, Germany, as part of her preparation for the second world war, encouraged the development of bauxite production in all the countries near her that contained this valuable aluminum ore. She was probably the world's greatest producer and consumer of aluminum in 1941, and the production was based entirely on ores imported from various parts of Europe. This long-range industrial strategy did much to alleviate the strain on her copper supply.

Japan, although producing enough copper for the industries not manufacturing munitions of war, required far more than could be supplied by domestic sources when she began her career of conquest. She anticipated the curtailment of copper shipments during her struggle with the United Nations and imported large quantities for a stockpile during the years preceding her attack on Pearl Harbor, December 7, 1941. This stock, supplemented by the loot from Asia and by her own artificially stimulated production, would be sufficient for several years of a war economy even though no other sources of copper were available.

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CHAPTER 16

Aluminum

Properties and Uses

LIGHTNESS, strength, electrical conductivity, and resistance to corrosion are outstanding characteristics of aluminum. Most of its uses are related to one or more of these qualities. Weight for weight, metallic aluminum is twice as good a conductor as copper but only 60 per cent as good a conductor volume for volume. The tensile strength of pure aluminum is about 55 per cent of that of copper but, because of its much lighter weight, an aluminum cable will support itself over a longer span than will a copper cable of comparable cross section. However, a slight addition of copper to aluminum makes an alloy that is very much stronger than either metal alone. Duraluminum contains only 4 per cent copper but has a tensile strength of 52,000 pounds per square inch as compared with a tensile strength of only 5,000 pounds per square inch for pure aluminum and 9,000 pounds per square inch for pure copper. Pure aluminum has a density of 2.70, melts at 659 degrees C., and boils at 1,800 degrees C.

In 1940 the transportation industry (air, land, and water) used 40 per cent of the aluminum produced in the United States; foundry and metal working required 23 per cent; machinery and electrical appliances, 9 per cent; cooking utensils, 6 per cent; electrical conductors, 5 per cent; building trim and building construction, 5 per cent; chemical industries, 5 per cent; metallurgy, 4 per cent; food and beverage equipment, 2 per cent; miscellaneous uses not listed above, 1 per cent.(12) Approximately half the weight of an airplane is due to aluminum. Its use in automobiles and streamlined trains is well known. A surprising amount of aluminum is used in electric cables. In 1939 there were 850,000 miles of steel reinforced aluminum cable in the United States. One thousand miles of large-diameter cable of this type was used in the construction of a 220,000-volt power line for the Bonneville dam project. Aluminum

foil has been successfully substituted for tinfoil in a number of instances. Foil is being used in increasing quantity for wrapping various kinds of food products and is an effective heat insulator. Aluminum paint is also finding increasing use and, like the foil, is an effective heat insulator because of its great reflecting power.

When powdered aluminum is mixed with iron oxide, the affinity of the aluminum for the oxygen is so great that once the material is heated the aluminum burns spontaneously, generating a tremendous amount of heat and liberating the iron from the oxide as molten iron. This is the base of one type of incendiary bomb, but metallic magnesium is more commonly employed. This type of reaction is also employed somewhat more constructively in the field of metallurgy. In the Goldschmidt process, powdered aluminum is used to reduce metallic oxides that are not easily converted to the native metal by the use of carbon alone. The affinity of aluminum for oxygen makes it an excellent deoxidizing agent, and it is used for this purpose in high-cost steels and other expensive alloys.

Various aluminum chemicals are produced from bauxite, almost the only ore mineral of aluminum. Bauxite is the basis of a strong, quick-setting cement that comes to its maximum strength very quickly. Where cement must soon carry a load, as in the lining of tunnels and other openings, the alumina cement is much preferred to Portland cement. Bauxite is also employed for fire brick. It is able to withstand relatively high temperatures and is not especially susceptible to chemical attack. Aluminum oxide and aluminum carbide are both excellent abrasives, and carborundum (aluminum carbide) is one of the most extensively used artificial abrasives manufactured.

Technology

Although aluminum is one of the most abundant elements of the earth's crust, only bauxite, a relatively uncommon hydrous oxide of aluminum, is used for ore in normal times. Bauxite, to be of acceptable grade either for metal production or for chemical use, must contain more than 50 per cent aluminum oxide. Both silica and iron are common impurities that are undesirable in the processes leading to metal production and are generally held to less than 4.5 per cent and 6.5 per cent, respectively. In some places alunite, clay, and leucite, a constituent of rare alkalic igneous rocks, have been used for the production of aluminum. These auxiliary sources are relatively unimportant, and the known reserves of bauxite are

so great that we may expect aluminum to be produced from this ore mineral for many decades to come.

Preparation of aluminum oxide is the first step in the metallurgy of aluminum. It is obtained by chemical treatment of bauxite. Any one of several methods may be employed, but the Bayer process is one of the most popular. Finely ground bauxite is digested in a hot concentrated solution of sodium hydroxide which dissolves the aluminum as a sodium aluminate but has little effect on the undesirable impurities, silica and iron. From this solution aluminum hydroxide is precipitated, filtered, dried, and calcined to produce alumina (Al_2O_3) of exceptional purity.

Molten cryolite, a sodium aluminum fluoride mineral, has the unique property of dissolving alumina and conducting electricity. This is the basis for the production of all commercial metallic aluminum. Alumina is added to a bath of fused cryolite maintained at a temperature of about 950 degrees C. Current is carried into the melt by several carbon anodes and fused aluminum collects as metallic liquid at the bottom of the cell and serves as the cathode. The aluminum thus formed contains less than 1 per cent of impurity, most of which is carbon. To obtain a metal of higher purity, anodes made of aluminum-copper alloy are used and metal that is more than 99.99 per cent aluminum is formed at the cathode.

Most of the aluminum used is consumed in industries where it is fabricated into semipermanent goods that ultimately return a large percentage of the aluminum to the scrap market. Before the extraordinary demand occasioned by the second world war, almost half of our aluminum was furnished by the scrap market. However, because of parts made of various other metals, most aluminum scrap is too impure to satisfy military needs where maximum strength and minimum weight are required. Thus, in times of emergency, secondary aluminum fails to supply the increased demand and a very heavy burden is put on the primary production facilities.

Geology

The two rocks that most commonly weather to form bauxite are the alkalic, silica-deficient igneous rocks, such as nepheline syenite, and the aluminum-rich sedimentary rocks, such as clay or shale. The geologic and geographic distribution of bauxite reflects the areas and periods where conditions have most favored rapid weathering and slow erosion. As would be expected, most of the bauxite deposits of the world are found in the tropical and warm temperate

regions of the world. Bauxite deposits are blankets or pockets of aluminum ore occurring at the present surface, if of recent origin, and are generally related to an unconformity if geologically ancient. However, some bauxite deposits have been eroded, transported by water, and redeposited as a bauxite-rich sediment at some distance from the point of origin. The process of transformation from clay or syenite to bauxite is one of slow but thorough leaching of silica accomplished mainly by the organic compounds generated by vegetation in warm, humid regions.

Bauxite Deposits of the World

The United States

The bauxite deposits of the United States are found in the northern part of the coastal plain of the southern United States and in the Appalachian Valley of the southeastern states. Bauxite of the coastal plains is of early Tertiary age and is found both as residual deposits lying on nepheline syenite and as sedimentary deposits derived from residual ores. The ore is found only at the contact of the Wilcox and Midway formations, beds of early Tertiary (lower Eocene) age.(1; 2)

The principal bauxite area is in central Arkansas, about eighteen miles southwest of Little Rock. Here syenite crops out over a considerable area and forms low hills. In early Tertiary times, these hills were probably blanketed by residual clay that carried lenticular masses of bauxite where the clay had been thoroughly desilicated. From these and similar centers of accumulation, bauxite spread into the early Tertiary sediments. Where it formed in situ, the bauxite passes downward into a blanket of clay that gives way to weathered syenite at greater depth. From the syenite hills, masses of bauxite can be traced down the flank and into the clay at the top of the Midway formation beneath the overlapping Wilcox shales and lignite.

Elsewhere in the Coastal Plains bauxite deposits were formed during the same period and reflect the same climatic conditions; but the source material was probably clay rather than syenite. The occurrence of a lignitic coal in the Wilcox formation immediately above the bauxite is indicative of the climate prevailing when the bauxite formed.

The deposits of the Appalachian Valley are associated with early Paleozoic limestone and dolomite. The bauxite occurs in irregular

pockets associated with clay and iron oxides and probably represents the alteration of clay that has accumulated in ancient solution cavities or "sinks" in the limy rocks. The reserves of bauxite in the United States are suggested in Table XIV.(2)

TABLE XIV

ESTIMATED BAUXITE RESERVES OF THE UNITED STATES IN LONG TONS AND PER CENT OF ALUMINA CONTENT (Al_2O_3)

Reserves (in long tons)	*Aluminum content (per cent)*
9,243,000	+55
8,898,000	50–55
8,439,000	45–50
2,438,000	30–45
Total 29,028,000	+30

South America

The moist subtropical climate of northern and central South America is ideal for rapid weathering of rocks, and it is probable that much undiscovered bauxite exists in this region. However, the important deposits of British Guiana and Surinam, or Dutch Guiana, have been explored sufficiently to indicate that they contain large reserves. Many deposits along the Surinam, Cotica, and Coermatibo rivers in *Surinam* furnish a large amount of bauxite for export to Canada and the United States. The reserves have not been carefully estimated, but they are known to be enormous. The beds range in thickness to a maximum of 20 feet, and most of the commercial ore averages about 12 feet. Some of the bauxite apparently has been formed in situ by the weathering of underlying clay and shale. Other deposits show evidence of transportation, and it is probable that the original bauxite has been reworked locally to some extent by wave or stream action. In addition to the bauxites that occur along the river, large deposits are known in the interior where the deeply weathered hills of clay are capped by a blanket of bauxite.(7; 8)

The ores of *British Guiana* are similar to those of Surinam. Some bauxite has been exported from *Brazil*, but little is known about the Brazilian deposits. The shorter haul from the north coast of South America to the consuming centers in North America should give the deposits in Surinam and British Guiana a distinct economic advantage over those in Brazil.

Africa

Bauxite has been reported from several localities in Africa, and large reserves are known to be present in the *Gold Coast*. The ore has formed from the weathering of clay shales. It is extensive, of good grade, and will undoubtedly be an important source of aluminum some time in the future. In the four chief areas that have been investigated, reserves are estimated to total nearly 230,000,000 tons.

Substantial amounts of excellent bauxite have been found also in the Atlas mountains of *French Morocco*. These deposits have not yet been exploited.

Europe

Rich bauxite ores occur through a wide zone in southern Europe. Nearly all ore is closely related to limestone and occurs at erosional unconformities above limestone beds of Jurassic, Cretaceous, and early Tertiary age. The bauxite occurs in pockets in much the same fashion as that found in the Appalachian Valley, and probably has a similar origin.

France is the largest producer of bauxite in Europe, and its bauxite industry is centered on the eastern side of the Rhone Valley near the Italian and Swiss boundaries. Much of the ore is found as pockets in the lower Cretaceous limestone, but some occurs as definite sedimentary beds interstratified with limestone. The bauxite contains a high percentage of aluminum and has little silica. The reserves of bauxite in France are estimated at approximately 50,000,000 tons.(3; 5)

Hungary is the second largest producer of bauxite in Europe and contains the largest reserves known in the continent. Nearly all of the bauxite is mined in the Vert district where the reserves are estimated at 250,000,000 tons. The principal deposits are southwest of Budapest at Gant and Helimba. They are found near the surface in depressions and pockets in an upper Triassic dolomite, and in places are overlain by beds of Eocene age. Some of the deposits are 60 feet thick. The Helimba district, 95 miles southwest of Budapest, has the most extensive deposit in Hungary. The bauxite bed is from 20 to 33 feet thick and is overlain by Eocene beds that in places form overburdens of approximately 200 feet. The reserve is estimated at 130,000,000 tons but is of lower grade than that of the extensive deposits at Gant. It contains from 41 to 50 per cent

alumina and 21 to 29 per cent iron oxide, as well as 2 to 5 per cent silica.(11)

Yugoslavia and Italy commonly produce nearly the same amount of bauxite and rank fourth and fifth in the production of the world. The bauxite deposits of *Yugoslavia* are found in a southeasterly trending belt that extends from Istria along the Dalmatian coast into Montenegro. The deposits occur as pockets in upper Cretaceous limestone. None of the Yugoslavian deposits is a definite sedimentary bed. The bauxite deposits of *Italy* are a northeastward continuation of the Yugoslavian belt and in this belt also the bauxite lies in pockets in upper Cretaceous limestone. The individual deposits are commonly from 90 to 300 feet long, 16 to 48 feet wide, and up to 90 feet deep. The ore averages 50 to 60 per cent alumina, 15 to 25 per cent iron oxide, 2 to 6 per cent silica, and 2 to 3 per cent titanium oxide. The reserves in Istria are at least 15,000,000 tons, sufficient to keep up the annual production of 300,000 to 400,000 tons for many decades. The Yugoslavian reserves are estimated at 100,000,000 tons.(11)

Like the bauxite deposits of Yugoslavia, those of *Greece* are in the southeasterly trending belt of Cretaceous rocks that follows the eastern side of the Adriatic Sea. The best deposits are near Mt. Parnassus. The bauxite occurs at the unconformable contact of Jurassic and Cretaceous limestones as a bed which ranges in thickness from 15 to 65 feet. The beds are folded and the ore thus far exploited occurs at the crests of anticlines. The bauxite contains 55 to 60 per cent alumina, 22 to 27 per cent iron oxide, and although much of it runs less than 4 per cent silica, some of it contains as much as 35 per cent and has to be treated by the special Bayer wet chemical process. Ten million tons of ore have been proved, and it is probable that the reserves of all grades are five times this figure. Prior to the invasion of the Germans in 1940, domestically owned companies raised most of the ore and shipped it to aluminum plants in Norway, Japan, Germany, and the United States. Both German and British companies were actively exploring concessions in 1939 when war was declared.(11)

In the *Soviet Union* the production of bauxite began in 1931. It increased from 11,000 tons in that year to more than 250,000 tons in 1940. In spite of extensive exploration during this period the known reserves are not large. The most productive deposits are those at Tikhvin, approximately 150 miles southeast of Leningrad. About 2,000,000 tons have been proved in this locality, but the

bauxite is low grade, containing from 42 to 48 per cent alumina, 10 to 20 per cent silica, as much as 26 per cent iron oxide, and 3 to 5 per cent lime. Bauxite of a better grade is found on the eastern slope of the Ural Mountains, near Sverdlovsk, and nearly 4,000,000 tons of ore have been proved. This bauxite contains approximately 58 per cent alumina, 3.7 per cent silica, and 26 per cent iron oxide. Several other deposits have been found in the Urals and some are known in Kazakstan and eastern Siberia. As compared with the countries of eastern Europe, however, only meager resources of bauxite have been discovered.(3)

The *United Kingdom*, *Germany*, and *Scandinavia* all are deficient in bauxite and depend on imports for their aluminum industries.

Asia

Extensive deposits of bauxite are known in the central provinces of *India*, some of which are of excellent grade. However, the high cost of shipping bauxite from India to the European market has prevented their exploitation except on a small scale. In contrast, the large bauxite deposits of the *Netherlands East Indies* are close to water transportation. The principal deposits are on the islands of Bimpan near Singapore and Banka just off the east coast of Sumatra. The ore was shipped to Germany and Japan prior to the second world war.

Extensive deposits of bauxite have been reported in north *China* in the vicinity of Kaiping, Czechwan, and Poshan.

Production and Consumption

The chief consumers of aluminum are, of course, the highly industrialized countries. Because aluminum requires electricity for its production, many countries where electricity is cheap produce substantial amounts of aluminum even though they do not mine bauxite and consume comparatively little of the metal produced. The imports of bauxite by nations producing aluminum but no bauxite can be estimated when it is known that approximately four tons of bauxite are required for one ton of aluminum metal. The production of bauxite and aluminum for representative years is given in Tables XXIII and XX, pages 354 and 351.

For many years the United States produced and consumed more aluminum than did any other country; but early in the nineteen-thirties Germany began developing her aluminum industry on a grand scale, and in the early part of the second world war she reached

and surpassed the United States both in production and consumption.

The expanding use of the light metal is reflected in the persistent increase in the world's output during the last decade. It is probable that the increased demand has been occasioned by the universal enlargement of the air arm of the various military establishments of the leading industrial nations. Nearly 70 per cent of the weight of the airframe and 23 per cent of the engine and propeller of the average military airplane are made up of aluminum. The average weight of a training plane is about a ton, of the interceptor about 2.5 tons, and of the heavy bombers about 15 tons. The world's consumption of aluminum increased from 260,000 tons in 1935 to 1,177,000 tons in 1941. It is believed that in 1942 the demand for aluminum in the United States exceeded a million tons as a result of the tremendous expansion of the United States war industries, and the consumption may have equaled the entire world output of primary aluminum for the previous year. Nearly all our apparent consumption of 227,000 short tons of primary aluminum metal of 1940 was supplied by domestic production. Of this figure, only 17,400 tons represents imports. However, the United States leaned heavily on imported bauxite to make the remaining 209,600 tons, some of which represented stock carried over from 1939. Our consumption of bauxite was 959,000 tons, and 630,000 tons were imported, chiefly from British and Dutch Guiana.

Almost all of the aluminum produced in America is in the hands of the Aluminum Company of America (Mellon interests) and the Reynolds Metals Company.

Canada

Canada produces no bauxite, but because of a favorable situation with respect to shipping and power, one of the largest aluminum plants in the world has been built in Arvida, Quebec. This plant is operated by a subsidiary of the Aluminum Company of America and much of the aluminum produced is exported to the United States. The United States and Canada are the only countries in the western hemisphere that produce aluminum. One of them has no ore, and the other produces only about one-third of its requirements.

Germany

None of the bauxite mined in Germany is used for the production of aluminum. For this metal, of which she produced more than

Commercial Control

Aluminum production in the United States and Canada is controlled by American capital, as is the bauxite of British Guiana and Surinam. It should be noted that the production of metallic aluminum is in the control of a relatively few powerful financial interests, whereas bauxite is produced by a far wider group. The Aluminum Company of America dominates the aluminum industry of the United States and Canada and has a substantial interest in the aluminum industry of Great Britain, France, Italy, and other European nations. American capital formerly controlled about one-fourth of the French production. German capital controlled some of the Hungarian production, some of the Greek production, and a substantial amount of the Yugoslav production. Most of the Hungarian output is domestically owned and produced, and most of the Greek output is in the hands of Greek citizens. Hungarians also control a substantial amount of the Yugoslav industry. Although considerable foreign capital was invested in the bauxite mines of France, all the aluminum plants are controlled by French capital. However, French capital controls most of the French bauxite and is interested in that of Yugoslavia also.(3)

It is apparent that American capital has a monopoly on the aluminum of the western hemisphere and dominates the aluminum industry of the entire world. French, British, and Hungarian capital all participate to a considerable extent in the production of European bauxite, but German production facilities so far exceed those of other European countries that German capital occupies a position in the aluminum industry of Europe comparable to that of American capital in the North American aluminum industry. A little less than half the bauxite produced in the world and a little more than half the metal output is controlled by United States and Canadian capital.

In summary it may be said that most of the metal produced is controlled by the domestic capital of the countries in which the aluminum plants are located, but that some foreign capital is invested in many of them. Foreign capital participates in the mining of bauxite to a much larger extent than in the production of aluminum. An increasing amount of bauxite may be expected in the Dutch East Indies, Malaya, and China.

any other country in the world in 1939 and 1940, Germany must depend entirely on imported ore. More than a decade before the war, shrewd Germans saw the possibility of developing an aluminum industry that would in part compensate for a copper shortage and would also play a vital part in building up a strong military machine. The Reich soon adopted an aggressive policy of stimulating the production of bauxite in countries near by where there was a minimum risk of suspended operations during a war with England and France. This policy is clearly reflected by the changes in importance of the sources of her imports for 1932–1937. (See Table XV.) In 1940 Germany's estimated consumption of primary alu-

TABLE XV

CHIEF SOURCES OF GERMAN BAUXITE IMPORTS 1932–1937
(in Metric Tons)*

Sources	*1932*	*1933*	*1934*	*1935*	*1937*
France	69,564	114,134	120,451	75,081	95,037
Hungary	68,228	53,176	109,851	218,149	472,313
Yugoslavia	39,831	38,832	77,274	150,397	405,825
Italy	21,714	29,743	16,250	56,424	111,271
Total †	200,731	239,062	326,465	505,485	1,313,152

* (3 ; 14)
† Total includes minor sources not listed.

minum reached 250,000 tons and almost all the metal was produced within Germany itself.

France, Italy, and the *Soviet Union* are the only European countries that produce substantial amounts of bauxite and that also produce 35,000 tons or more of aluminum. Italy's industry is especially favored by the proximity of water power to bauxite deposits. Cheap hydroelectric power is responsible for the appearance of Switzerland and Norway on the list of aluminum producers.

The approximate aluminum consumption of the *United Kingdom* during 1940 was 135,000 tons of which approximately two-thirds was imported as metal and the remaining third as ore to be converted into aluminum at British plants. The consumption of the *Soviet Union* was approximately one-half that of the United Kingdom. It is estimated that approximately half of the aluminum produced in the Soviet Union came from domestic ores. The *Japanese* production of 32,000 tons of aluminum in 1940 was made from ore imported from the Dutch East Indies. The remainder of the 45,000 tons of primary aluminum that Japan consumed was supplied by imports of the metal.

National Policies

The United States has endeavored to encourage the production of aluminum and bauxite by imposing import duties of a dollar a ton on aluminum ore and three to four cents per pound on aluminum alloys and scrap. When it became evident that the United States would be drawn into the European conflict in 1941, the federal government began financing extensive surveys of the bauxite reserves of the United States and Latin America. Loans and subsidies were made available for the construction of new aluminum plants in anticipation of the tremendous expansion of the industry required by the war program upon which the country soon embarked. In the United Kingdom facilities were available for production of a substantial amount of her aluminum requirements from imported bauxite. However, because of the scarcity of bottoms after Dunkirk, it became increasingly desirable to reduce the bauxite to aluminum before shipment to Great Britain, and thus save hauling four times as much raw material.

German policy with respect to aluminum has already been touched upon briefly. German capital was encouraged to build aluminum reduction plants of large capacity and to operate upon ore from nations unlikely to be ranged against Germany in the event of a European war. Efforts were made to assure an adequate supply of bauxite by exerting military or diplomatic pressure rather than by commercial acquisition. However, as a precautionary measure Germany accumulated substantial stockpiles of aluminum prior to September 1939, when war was declared. Italy and Hungary produce more bauxite than they consume and have, of course, encouraged domestic capital to build up an aluminum industry.

Japan has almost no bauxite, but she installed aluminum reduction works with a capacity of about two-thirds of her normal consumption; these works are dependent entirely upon imported ore. Japanese commercial control was set up in Malaya, but until the invasion of the Dutch East Indies most of the bauxite upon which Japan depended was under the commercial control of the Netherlands. (See Figure 40.)

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CHAPTER 17

Lead

Properties and Uses

LEAD is a soft, heavy, fusible metal with a density of 11.34 and a melting point of 327 degrees C. Although pure lead is extremely soft and malleable, the addition of a small amount of antimony greatly increases its strength and hardness; "hard lead" is a synonym for antimonial lead. Lead and many of its alloys and compounds are unusually resistant to corrosion. Most of its industrial uses are due to "workability" and capacity to withstand chemical attack. Its resistance to the corrosive action of sulphuric acid makes lead ideally suited for storage batteries, its most important use. For many years the second largest field has been in covering electric cables; a lead sheath is equally effective in protecting copper cables from water or air. A substantial amount of lead is converted into the pigments white lead and red lead, which have an extremely high covering power and are resistant to weathering. In late years, white lead has been somewhat replaced by titanium oxide pigments.

In 1937, out of a total consumption of 678,700 tons in the United States, 192,000 tons of lead were used for storage batteries, 90,000 tons for cable coverings, 86,000 tons for white lead, 57,000 tons for red lead and litharge, 45,000 tons in the building industries, 39,500 tons for ammunition, 22,000 tons for solder, 21,700 tons for lead foil, 15,000 tons for bearing metal, and 17,000 tons for type metal.

As red lead, litharge, and white lead are used in chemical industries and in making paint, they must be regarded as permanent withdrawals from our lead stock. In most of its other uses, lead is classed as a nonexpendable material and, as compared with zinc, has a far higher secondary recovery. Thus, nearly 80 per cent of the lead put on the market may be returned eventually as scrap, whereas in the zinc industry nearly half is consumed by the galvanizing industries and must be regarded as permanently lost.

Technology

The chief ore mineral of lead is its sulphide galena; but in some places the lead carbonate cerrusite, and the lead sulphate anglesite, are also ore minerals. Lead is easily reduced from its ores in a blast furnace after the ore has received a preliminary roast to remove most of the sulphur. The product of the blast furnace is known as base bullion and is generally further refined before it is placed on the market. Many lead ores contain an appreciable amount of silver, which always accumulates in the base bullion when the ore is smelted and may be removed by one of several methods. Commonly a small amount of zinc is added to molten lead, and as the charge slowly cools the silver and zinc form a crust which is skimmed off and further purified. Lead may also be purified by electrolysis. The presence of an appreciable amount of zinc in lead ores is a serious handicap in smelting. Some of the zinc volatilizes and condenses in the cooler part of the furnace, to the decided detriment of the equipment, and some alloys itself with the base bullion making an inferior product. As a result, lead ores are penalized if they contain more than 8 per cent of zinc. Before the differential flotation process was successful, large sulphide bodies containing complex mixtures of lead, zinc, and other metals were left untouched or were treated for only a few of the metals. At present, such ores can be successfully milled and an excellent recovery made of both galena and the zinc sulphide mineral sphalerite. To avoid dust losses, the fine-grained flotation concentrates are sintered before smelting.

Substitutes

Zinc-white and titanium-white pigments compete with white lead and make fairly good substitutes. Lead is one of our cheapest metals, the average cost ranging from 3.5 to 4 cents a pound. Thus the metallurgist has little incentive to find substitutes for lead; rather he attempts to find places in which lead may be substituted for a more expensive metal. Scrap lead may be regarded as a substitute for new lead ore, and commonly 50 to 60 per cent of the lead produced in the United States is secondary. In contrast, secondary zinc makes up only from 20 to 30 per cent of the zinc produced. Thus approximately twice as much scrap lead as scrap zinc is brought back into the market each year. This circumstance has been a major factor in gradually depressing the price of lead to less than that of zinc.

Geology

Most lead ore is found in limestone replacement deposits, or "mantas," not closely associated with igneous rock and in veins whose magmatic affiliations are more apparent. Nearly everywhere zinc is associated with lead ores, and in veins both are usually accompanied by some silver, copper, gold, and antimony. Replacement deposits comprise bodies of limestone that have been slowly transformed into galena by almost simultaneous solution of the limestone and precipitation of lead sulphide. Locally where solution has forged ahead of precipitation, these ore bodies contain large caves lined with beautiful crystals of the ore minerals. Commonly the ore solution followed rather definite channels, leading from a deep-seated igneous source upward through cracks and crevices in the limestone toward a distant outlet at the earth's surface. As a result, ore bodies usually have a definite trend corresponding to that of the fractures open during mineralization. They may be localized just beneath impervious beds or under intrusions that served as sloping walls along which the solution moved toward its destination at the surface. Much of the world's lead comes from deposits of this type, but a substantial amount is also found in veins. The walls of some veins have been extensively replaced by lead and zinc sulphides; in others the ore was precipitated only in open parts of the vein fissure.

Lead and zinc are found in rocks of all ages, but the most extensive deposits are related to Laramide and Hercynian orogeny. Limestone replacement deposits or mantas of Laramide age are found in Mexico and the southern Rocky Mountain states. The great replacement veins of the Coeur d' Alene district in Idaho are in metamorphosed late pre-Cambrian sandstones; but the age of the mineralization is probably much later and is generally regarded as late Cretaceous or early Tertiary. Dikes and irregular intrusive bodies are associated both with the Idaho deposits and those of the Southwest. In contrast, the enormous lead-zinc deposits of the Mississippi valley as well as those of Silesia in Europe are remote from known intrusives. However, they exhibit many characteristics of ore bodies related to igneous rocks, and there is an inclination on the part of most students of mineral deposits to classify them with deposits formed by magmatic solutions.(2) In both regions the age of the ore deposits is uncertain.

Geology of Major Lead Districts

The United States

One of the most remarkable metallogenic provinces in the world is found in the flat plains of the Mississippi valley between northern Oklahoma and southern Wisconsin. For many years this region has produced nearly half the lead of the United States. Scattered through this area are many lead and zinc replacement deposits in limestones ranging in age from Cambrian to lower Carboniferous. In the vicinity of most of the ore bodies, the limstones are completely recrystallized to a coarse dolomite and to fine-grained silica known as chert or jasperoid. Much of the ore is in transition zones where chertified limestone grades into coarse dolomite. Some of it lies in horizontal pipe-shaped masses, but much of it occurs in flat irregular sheets. Within each district the ore is confined to a few definite beds, but these stratigraphic horizons vary from one district to another.(2)

The second largest producing area in the United States is the Coeur d' Alene district in the wooded mountains of Idaho. The late pre-Cambrian quartzites and slates of this region are cut by small masses of granite which are probably related to the extensive mineralization that followed their intrusion. All the rocks have been severely faulted. The two principal producing areas lie about 13 miles apart, and many geologists believe that both were formerly in a continuous belt which was broken by the great Osburn thrust fault that now separates them. Silver-bearing lead and zinc deposits are found in wide, steep fissure veins and in closely related replacement deposits. Some veins have been followed along the dip to a depth of 4,600 feet, and there is reason to believe that the ore continues to a still greater depth.

Mexico

In Mexico lead-silver and lead-silver-zinc ores occur as replacement deposits in the thick upper Mesozoic limestones that are widespread in the Mexican plateau region. Santa Eulalia, Chihuahua, Mapimi, Durango, and Sierra Mojada are the most important lead-producing districts. Primary sulphide ore occurred in flat-lying irregular bodies, but it has been so thoroughly oxidized that most of the ore mined consists of cerrusite and anglesite rich in silver. Many of the ore shoots are almost horizontal pipe-shaped bodies

that lie at different levels and are connected by nearly vertical chimneys of ore. Lead-silver veins are worked in many places in Mexico, but they furnish only a small proportion of Mexico's lead output.

Canada

The largest individual lead-zinc deposit in the world is probably that of the Sullivan mine at Kimberly, British Columbia, 85 miles north of Idaho. The miners who exploit this great deposit are famous for their mining efficiency, their prize flowers, and their hockey teams. Kimberly is probably the only place in the world where 1,200 miners and mill men are regularly given a half holiday with pay to watch their hockey team do battle. The enormous lead-silver ore body is a replacement deposit in folded late pre-Cambrian sediments similar in age and lithology to the slates and quartzites of the Coeur d' Alene district of Idaho. The slates are invaded by a small mass of granite (granodiorite) about five miles southeast of Kimberly, and the rocks at the mine are cut by many altered dikes of mafic rock. The ore body is a blanket of solid sulphide much of which is iron sulphide (pyrrhotite). Lead and zinc together make up about 16 per cent of the ore, which also contains 4 ounces of silver per ton and a small amount of tin and antimony. The ore body ranges from 150 to 250 feet in thickness and follows along the eastern side of a northerly trending anticline for a distance of a mile. It is at least 3,500 feet wide, but the eastern limit has not been ascertained because of the depth at which the ore lies in this part of the ore body.

South America

Acquilar, Argentina, and Cerro de Pasco, Peru, are substantial lead producers. At Acquilar, north of Jujuy, replacement deposits occur in faulted Paleozoic limestones which have been intruded by granite. Several million tons of ore containing 11.5 per cent lead, 16.25 per cent zinc, and about 9 ounces of silver per ton have been developed.(10)

Germany

Most of the lead mined in Germany is a by-product of zinc mining; but in a few places lead is the chief metal sought. The geology of some of the more important zinc-lead districts is discussed briefly on page 312. Two important lead-mining districts are found in

the Mechernicher-Knotten area southwest of Cologne and in the Ramsbeck district to the northeast. In the former, the ore is a bedded deposit up to 5 feet thick. In the Ramsbeck district ore lies in gently dipping veins that cut metamorphosed Devonian beds. The Grund Mine in the Harz Mountains exploits lead-zinc ore in steep veins from 3 to 30 feet wide which cut metamorphosed Carboniferous rocks. From this mine approximately 9,000 tons of lead and 1,500 tons of zinc are produced annually.(10)

Australia

One of the great ore bodies of the world cropped out at Broken Hill in the desert region of southern Australia. The value of lead, zinc, and silver taken from it since its discovery in 1883 is more than $900,000,000 and it is still the mainstay of Australian lead and zinc production. The Broken Hill vein has been opened for a length of more than 3 miles, mined to a depth of more than 2,200 feet, and is more than 100 feet thick over considerable distances. It is essentially parallel to steeply tilted and folded metamorphosed pre-Cambrian sediments and has a saddle-shaped cross section. The ore contains about 15 per cent lead and 15 per cent zinc. Unlike typical lead-zinc replacement deposits in limestone, the minerals associated with the ore at Broken Hill suggest a hypothermal deposit, one formed under conditions of extreme pressure and at high temperature from emanations given off by a near-by magma.

Burma

The only large lead-zinc deposit in Asia outside of the Soviet Union is worked by the Bawdwin Mining Company in northern Burma just south of the Chinese border. Interbedded volcanic ash and early Paleozoic sediments are cut by a wide, steep, northwesterly trending fault zone along which metallizing solutions rose. The volcanic ash (rhyolite tuff) was converted into a nearly solid mass of lead-zinc-silver sulphide ore through a width of 20 to 60 feet, and the high-grade ore is bordered by a thick envelope of lower-grade disseminated ore. Differing from most mines, which work from "the top down," ore in the Bawdwin mine is mined from "the bottom up," as the main working level is a tunnel that cuts the ore body far below the surface. The ore mined averages 19 per cent lead, 11 per cent zinc, and 14.5 ounces of silver per ton. The reserves in 1940 were estimated as more than 11,000,000 tons of ore. (7; 14; 18)

Production and Consumption

During the late nineteen-thirties the world production of lead averaged just under 1,500,000 metric tons annually. None of the leading industrial nations produce as much lead as they consume. The United States, although the largest producer of lead in the world, commonly imports a few thousand tons more than she exports. All the other industrial nations import substantial amounts. Mexico, Australia, Canada, Burma, Yugoslavia, and Newfoundland are the chief producers of lead and zinc ore with a large surplus for export. During the periods of high industrial activity the world's production is approximately 2,000,000 tons. Production during some representative years is shown in Table XXXVI.

The United States

Approximately 45 per cent of the lead ore produced in the United States comes from southeastern Missouri; another 7 or 8 per cent is mined farther west in the Tri-State district near the junction of Kansas, Missouri, and Oklahoma. Together these two areas in 1940 contributed 205,000 tons out of the United States total of 457,000 tons of new lead. The Coeur d' Alene district of Idaho supplies approximately 22 per cent of the United States total. Galena-bearing veins and replacement deposits are found in many other western mining camps, but several of them are more noted for production of copper, silver, or gold than for production of lead. The Bingham district of Utah, the premier copper camp of the United States, is the third largest lead producer and contributed approximately 38,000 tons of ore in 1940, an amount equivalent to 8.3 per cent of the country's production. The Park City region of Utah produced a little more than half as much as Bingham. These five districts normally produce from 75 to 80 per cent of the lead ore of the United States; nearly all the remaining 20 to 25 per cent comes from dozens of smaller districts scattered throughout the western United States.

In years of normal industrial activity, the Unitel States consumes between 600,000 and 700,000 short tons of lead, but a third of this is generally furnished by scrap. However, the expanded armament program increased our total to approximately 900,000 tons in 1941. The following year consumption probably proceeded at a rate of about 90,000 tons a month, of which about one-third was imported, chiefly from Mexico, Australia, Canada, and Peru.

This heavy demand greatly accelerated the rate at which our mines are depleting, but ore reserves are adequate for several years. After the abnormal stimulation due to the war has been withdrawn, the United States may expect to be much less self-sufficient in lead than it was prior to the second world war, and will either import substantial quantities of lead or burden the consumers with tariff-maintained prices.

Mexico

Mexico stands second only to the United States in the amount of lead produced annually and usually mines and smelts well over 200,000 tons of lead each year. Although Mexico has been one of the leading producers of lead-silver ore for centuries, her reserves are probably large enough to maintain her present rate of production for many years. If it were not for the heavy tariff imposed by the United States on imported lead and lead ore, Mexico would undoubtedly increase her shipments here, as was done in 1942, and her total output would rise accordingly. Most of the Mexican lead normally moves to France, Germany, and other European countries, and the withdrawal of this market due to the British blockade worked a severe hardship on the Mexican lead producers in 1940 and 1941. American and British capital controls most of the smelters and many of the mines, but the United States consumes almost no Mexican lead in normal times, and Great Britain takes less than 15 per cent of Mexico's output.

Canada

During the nineteen-thirties, 98 per cent of Canada's annual output of about 200,000 tons of lead came from British Columbia and most of it must be credited to the Sullivan mine at Kimberly.(18) Ore reserves at the Sullivan mine are adequate to maintain the usual production of 6,500 tons of ore a day for a decade or more. In 1939 and 1940 much of Canada's output was bought by Japan, but the United Kingdom was its chief consumer in 1941. The property is controlled by the Canadian Pacific Railroad Company.

Newfoundland

The Buchans lead-zinc mine in southwestern Newfoundland accounts for nearly all the 20,000 tons of lead mined in the island colony.

South America

The lead production of South America is small but increasing. The chief producer is Argentina, and almost all its lead is mined in the Acquilar district. The country consumes about 14,000 tons of lead a year, and any surplus over this figure is available for export.(10; 16) Argentina first achieved self-sufficiency in 1939. Peru has many lead-zinc deposits, but its production was small until 1937. A large reserve of ore was developed at the famous Cerro de Pasco copper mines, and as this ore began to come from the mine, Peruvian production increased greatly. In 1940 about half of the ore mined was exported and about half was taken by Cerro de Pasco's Oroya smelter, which poured 24,310 metric tons of lead in 1940. The European conflict stimulated exploration in the southern part of São Paulo, Brazil, and several deposits of silver-lead ore were found and rapidly developed in 1941 and 1942.

Belgium and Luxembourg

The famous Moresnet lead-zinc district includes part of Belgium, Luxembourg, and Prussia and during the first part of its long history furnished a substantial part of the world's zinc and lead. Mine production of lead and zinc in both Belgium and Luxembourg has been insignificant for many years, but the lead- and zinc-smelting industries of Belgium, born years ago when her mines were among the leading producers in Europe, have continued long after becoming completely dependent on imported ore. Ninety-three thousand tons of lead were smelted and approximately 53,000 tons consumed in 1937. The ore came chiefly from Yugoslavia, Sweden, Bolivia, Australia, Canada, and the United Kingdom. In addition, however, Belgium imported some 28,000 tons of pig lead, 80 per cent of which came from Mexico.(10; 18)

France

In 1937 France consumed 108,000 tons of lead. Only 3 per cent of her requirements are usually mined in France, but from 20 to 30 per cent is supplied by her colonies. About 40 per cent of the lead used is smelted in France from imported ores. Her lead imports are commonly divided almost equally between Tunisia, Belgium, Spain, and Mexico.

Germany

A substantial amount of lead is mined in Germany, but prior to the second world war both her lead and her zinc industry leaned heavily upon imports of metal and ore. Her consumption, which amounted to 172,000 tons of lead in 1935, increased to 213,000 tons in 1936 and to 235,000 tons in 1937 as her preparation for the coming conflict made increasingly heavy demands upon her metal industry. Of the 100,000 tons smelted annually within her borders during these years, only about 45,000 tons were from domestic ores. More than half of the imported pig lead came from Mexico. The remainder represented many sources, chief of which were Great Britain, Spain, Australia, Belgium, and the United States. The imported ore also was from many countries, which, listed in the order of their contributions, include Yugoslavia, Canada, Great Britain, Burma, and Bolivia.(10)

Italy

Italy is nearly self-sufficient in the production of lead and exports zinc ore in considerable quantities. Of the 50,000 tons of lead used annually in Italy, from 35,000 to 40,000 tons are produced from zinc-lead ore chiefly mined in Sardinia. The high ratio of zinc to lead in the Italian ore made it necessary to produce a large surplus of zinc in order to satisfy domestic lead requirements from her deposits in Sardinia and at Trieste.

Spain

During the latter half of the nineteenth century Spain was the leading producer of lead in the world. She surrendered first place to the United States in 1898 when still producing nearly 25 per cent of the world's output. The mainstay of the production has been the districts of Linares and Cartagena in southern Spain, where both Phoenicians and Romans mined more than 2,000 years ago. Although the peak year did not come until 1913 when Spain greatly increased her production and established a record of 202,997 tons, there was an almost steady decline from 198,000 tons in 1898 to 27,000 tons in 1939. The drop from 70,000 tons in 1935 to 46,000 tons in 1936 was a repercussion of the Spanish Civil War. The slowness with which lead production increased after that war reflects the government policy of reducing the profit margin of the mine opera-

bors to a minimum in an effort to obtain a larger revenue from the ore.

The Soviet Union

The Soviet Union contains many scattered lead-zinc deposits but has had difficulty in obtaining its requirements from domestic ores. In 1936 it consumed 85,000 tons of lead, of which 28,000 tons came from domestic ores. This tonnage fell far short of the announced plan of producing 115,000 tons of lead from home ores. The lead comes largely from ores in which the zinc-to-lead ratio is about two to one, and it is doubtful whether the Soviet Union's requirements of lead will ever be completely met by domestic production.

The United Kingdom

Most of the lead mined in the United Kingdom comes from several districts in northern England, but the domestic production is far from sufficient to satisfy Britain's normal requirements of 300,000 to 400,000 tons of lead a year. During the nineteen-thirties England produced from 40,000 to 50,000 tons of lead from domestic ore. The remainder of her requirements were furnished largely by Australia, Canada, and Burma. By drastic restriction of civilian uses, Great Britain reduced her requirements of lead in 1939 and 1940 to approximately 250,000 tons of primary lead.

Yugoslavia

Most of the ore mined in Yugoslavia is exported to various European smelters. Although she produced nearly 70,000 metric tons of lead in ore annually in the late nineteen-thirties, only 10,000 to 14,000 tons of lead was smelted within her borders. Her domestic consumption is small. Nearly all the lead-zinc ore comes from the Stantrg mine about 50 miles north of Cetinje. The reserves are estimated at nearly 3,000,000 metric tons containing 9 per cent lead and 8 per cent zinc.

Africa

Several small districts contribute to Africa's meager production of lead and zinc. The largest deposits are those of the Rhodesian Broken Hill Company in northern Rhodesia about 100 miles south of the Congo border. These ores contain a substantial amount of vanadium (see page 250). Somewhat similar deposits are known in Algeria and Tunisia, the only other areas in Africa that have

an appreciable production.(3) Unless extensive and very cheaply mineable bodies of lead ore are discovered in Africa, this continent is unlikely to supply more than a small percentage of the lead consumed in the world annually.

Australia

Australia has for many years been one of the world's leading lead producers and commonly contributes well over 200,000 tons to the world total. Most of the lead comes from the Broken Hill lode in New South Wales, but a substantial amount can be credited also to the Mount Isa mine in Queensland. Reserves at this mine are estimated at about 28,000,000 tons of ore. Most of Australia's lead is exported to Europe. Japan normally took only a few thousand tons. In 1940 and 1941 Australia increased her production and sent most of it to the United Kingdom. However, as previously noted, the United States obtained a substantial amount of ore from Australia in the latter part of 1941 and in 1942.

Asia

Nearly all of Asia's lead and zinc production must be credited to the Bawdwin mine in the upper Shan States of Burma. The mine exploits rich silver-lead-zinc veins near the Chinese frontier and produces from 70,000 to 80,000 tons of lead each year, all of which is exported.

Ninety-nine per cent of the known lead deposits of China are found in southern China in Hunan, Yunnan and Sikang provinces. Sufficient lead is produced to meet the small domestic demand, but none is available for export.

Japan produces only 10 per cent of her normal consumption and formerly drew heavily upon Canada for her imports. In 1936, out of a total of 98,000 tons of imported lead, Canada furnished more than 43,000 tons. The remainder came chiefly from Burma, the United States, and European countries.

Commercial Control

Most of the lead and zinc produced in the United States, Mexico, and South America is controlled by United States capital. Canadian capital controls Canadian production and Canadian and American interests jointly control the lead and zinc of Newfoundland. British capital controls the production of Australia, Burma, and Rhodesia and formerly participated to a marked extent in Spanish

production. Commercial and political control are identical in Italy, the Soviet Union, Japan, and Germany.

National Policy

It has been the policy of all the industrial nations to encourage both mine and smelter production of lead and zinc to the utmost within their borders. The United States has yielded to the importunities of domestic producers and has established a heavy import duty on lead and zinc both for ore and metal. Import duty on ore amounts to 1.5 cents a pound of contained zinc or lead, but in bullion and alloys the tariff is 1.75 to 2.25 cents per pound as of 1940. With the pre-war market price of about four cents per pound, this should have been ample to "protect" any justifiable American production.

The war economy which had become world-wide in 1941 required price control. Great Britain imported all her lead from her colonies and dominions during the first two years of the war, buying it at a fixed price, duty-free. Germany entered on a war economy long before any of the United Nations. In 1937 a board of control was established with power to indicate who might buy metals and to fix the price in the terms of sale. Every effort was made to stimulate domestic production, but in 1939 Germany was still producing less than half her needs of primary lead. With the successful conquest of Belgium and Yugoslavia, Germany obtained important smelting facilities and lead stocks as well as substantial ore supplies.

The entire Axis-controlled territory in Europe normally consumed about 40 per cent more than its smelter capacity and almost 150 per cent more than its entire mine production. An increasingly acute lead shortage was inevitable with the cessation of shipments from the New World and Australia. Italy endeavored to stimulate its lead production by levying a high import duty on lead and by prohibiting the export of metallic lead or scrap except under special permit. One hundred and seventy lire per ton was charged for imports of lead ore regardless of grade. In Spain, the Franco government rigidly controlled the price of lead after successfully defeating the Nationalists with the help of British acquiescence, German technicians, and Italian troops. Although the export price of lead was approximately $135 per ton, Franco allowed the mine operator only $46.50 per ton of lead in ore to cover both smelting charges and operating costs. However, the government sold lead

for $110 per ton for domestic consumption and, depending on the market and various other circumstances, a premium of $15 to $23 per ton was returned to the miners several months after the sales were consummated. This policy brought a substantial revenue to the government on the ore that was produced. The policy, however, discouraged the miner and accounts in large part for the low level to which Spanish production figures sank.

Japan increased her smelter capacity in 1939 and 1940, anticipating larger supplies of Asiatic ores and the curtailment of foreign supplies of pig lead. The outbreak of hostilities found her with a substantial reserve stock of lead on hand; her stockpiles of minerals and metals had been accumulated with such secrecy that although their existence was suspected, their size was unknown to the experts of the United Nations.

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CHAPTER 18

Zinc

Properties and Uses

Zinc is a soft white metal with a density of 7.1. It melts at 419 degrees C. and boils at 918 degrees C. It is only moderately resistant to corrosion, but resists oxidation much better than does iron. Although it is brittle at ordinary temperatures, it is malleable at about 120 degrees C. and can be rolled into sheets or drawn into wires at that temperature. Of the 719,000 tons of zinc consumed in 1940 by the United States, 287,000, or 40 per cent, was used in the galvanizing industry. To galvanize steel or iron the metal is dipped into a bath of the molten zinc. The coating of zinc that adheres to the metal when it is taken out of the bath is sufficient to ward off the attack of the elements for a long period of time and thus greatly enhances the life of thin steel sheets, tubes, wire, and wire cloth. The second largest use is in the manufacture of brass, and nearly a third of our zinc found its way into this alloy in 1940. Most brass contains from 70 to 85 per cent copper and from 15 to 30 per cent zinc, but for special purposes the percentage of zinc may be increased to over 50 per cent.

Zinc, in common with certain other fusible metals, is being used in increasing amounts for castings that do not require high strength. Such metal castings have the great advantage of being readily formed and rapidly duplicated by the use of metal molds. This is called the die-casting process. In 1940 die castings used 116,000 tons or approximately one-sixth of the metal consumed. A substantial amount of zinc is also used in battery cans, in glass jar tops, in photoengraving sheets, and in the automotive industry. Zinc sulphide is widely used as a pigment and is the basis of lithopone. Three per cent of the zinc produced goes to form zinc oxide, which finds its principal use as the pigment, zinc white. It is also an important pharmaceutical compound.

Substitutes

Iron can be protected from the weather by many methods other than that of galvanizing, and as galvanizing accounts for 40 per cent of the zinc consumed, its curtailment would release a substantial amount of the metal for other uses. Brass is an important alloy and has so many industrial applications that it ranks as one of our most indispensable metals. During a war the amount of brass consumed increases greatly, and so far no adequate substitute has been found. In nearly all its other uses substitutes are available for zinc. Both lead and titanium oxides may be substituted for zinc white.

Technology

Zinc is found in a wide variety of minerals, but with a few exceptions, such as in the Franklin Furnace district of New Jersey, zinc ores of commercial value consist of the zinc sulphide, sphalerite (zinc blende), the zinc carbonate smithsonite, or the zinc silicate calamine. It is probable that more than 95 per cent of the zinc mined can be classed as sulphide ore. Most sphalerite ore contains from 3.5 to 20 per cent zinc and must be concentrated by gravity mills or flotation before it is ready for the smelter.

Because of its low boiling point, zinc ore cannot be smelted in the blast furnace as can lead ore. In a lead blast furnace zinc can be made to combine with a flux to form slag. At a few localities in the United States, for example, Garfield, Utah; Kellogg, Idaho; and East Helena, Montana, slags carrying more than 8 per cent zinc are treated in "fuming plants" to produce a fume suitable for treatment in zinc distillation refineries. Fuming plants are operated in conjunction with lead blast furnaces that are fed a charge unusually high in zinc; ore containing as much as 18 per cent zinc is acceptable in these furnaces, although ore having more than 8 per cent zinc is penalized at the ordinary lead blast furnace. The molten zincy slag from the lead blast furnace is poured into a special blast furnace maintained at a much higher temperature than the lead furnace by an intense air blast and powdered coal, which is introduced at the tuyers. The zinc in the molten slag is reduced to a metallic state by the coal, volatilized by the intense heat, cooled in a long series of condensers, and finally collected as an impure fume in burlap bag filters in a bag house. The fume contains more than 60 per cent zinc and can be produced at a moderately low cost.

Metallic zinc or spelter is obtained by two general processes—

electrolysis and distillation. As a preliminary treatment for both processes, sulphide ores must be roasted at low temperatures and converted to the oxide. The roast may then be leached by acid solutions and electrolyzed to form an extremely pure zinc sheet, or the roast may be treated in retorts. In this latter process oxides are mixed with hard coal and distilled in a refractory tube made of clay and carborundum. This retort is about 8 inches in diameter and 4.5 to 5 feet long. The condensers are small cones about 16 inches long that fit into the lower end of the retort and have an opening about 2.5 inches in diameter at the bottom through which the condensed liquid zinc may be drawn from time to time. The retorts are placed in banks of 20 or more arranged in tiers that slope gently downward and outward from the center of the retort furnace, and are usually heated by a gas flame. After the moisture is expelled from the charge, carbon monoxide forms and burns at the mouth of the condenser. When the carbon monoxide commences to burn, the zinc distills and collects at the bottom of the condenser. In spite of all precautions, 10 to 15 per cent of the zinc collects as oxide. The usual charge for a retort is only 100 pounds of mixed oxide and coal.

The retort method does not have a high efficiency because much zinc is lost in the process of volatilization and a substantial amount remains in the residue after the retorting. This process has changed but little since it was developed in Belgium two centuries ago. The presence of lead lowers the efficiency rapidly, and for this reason zinc ores containing more than 2 per cent lead are severely penalized.

Zinc ore, like copper ore, either moves to a coal field for smelting or to a source of cheap electric power for electrolytic refining. The inertia of invested capital may result in a smelter continuing to operate on ores imported from increasingly distant sources a long time after the ore deposits that brought it into being have been exhausted. These smelters must have certain advantages such as accessibility, cheap skilled labor, cheap coal, and favorable location if they are to remain in business.

Geology

Zinc is found chiefly as replacement bodies of sphalerite in limestone and in veins cutting rocks of all types and ages. In most deposits the sphalerite is intimately intergrown with sulphides of iron and lead, and some copper, antimony, arsenic, silver, and gold are generally present also. Oxidation usually destroys zinc min-

erals, and there is little secondary precipitation at depth. Most of the zinc dissolved in the oxidized zone is dissipated in ground water and completely lost. In this respect it differs profoundly from lead. However, in some places where the natural chemical environment is especially favorable, bodies of secondary carbonate and silicate form adjacent to oxidizing sulphide ores.

Major Zinc Districts of the World

The United States

The greatest zinc-producing area in the United States is the Tri-State district of northeastern Kansas and Missouri. The district is part of the Mississippi Valley lead-zinc province mentioned on page 295. The ore is similar in occurrence to the lead ores of districts near by, except in the relative proportion of galena and sphalerite present. The Tri-State ore consists essentially of sphalerite, iron sulphide (pyrite), dolomite, and chert with a minor amount of galena. The ore is coarse and easily concentrated and occurs in flat-lying Paleozoic limestones and dolomites at such shallow depths that cheap mining is possible.

About 50 miles west of New York City is one of the most remarkable ore deposits in the world. The unique zinc deposits at Franklin and Sterling Hill in Sussex County, New Jersey, jointly produced ore containing 91,406 tons of recoverable zinc in 1940 and are the only zinc mines in the state. The deposits are free from lead and sulphur and the zinc occurs in a suite of unusual oxide and silicate minerals, some of which are unknown elsewhere in the world. The ore is found in a much metamorphosed pre-Cambrian limestone at its contact with a thoroughly metamorphosed intrusive granite gneiss. Many theories have been proposed to account for the unusual ore body. It is believed by some that it represents a contact metamorphic sulphide ore body that was thoroughly oxidized and later metamorphosed.(13)

One of the largest zinc mines in the western United States is at Gilman, Colorado, 30 miles north of the famous old mining town of Leadville. The ore body is a typical manta or limestone replacement deposit. Paleozoic beds slope gently northeast and contain a thin layer of intrusive rock (andesite porphyry) of Laramide age between the Lower Carboniferous Leadville limestone and Middle Carboniferous conglomerates and micaceous shales. The top of the Leadville limestone was furrowed by ancient water courses and sink holes before the overlying rocks were laid down, and some of

these ancient channels served to guide metallizing solutions upward beneath the porphyry sheet shortly after it was intruded. The limestone was converted into dolomite, and then zinc, iron, copper, silver, and lead sulphides replaced dolomite sand and rubble in the cavernous water courses and attacked the solid bed-rock walls. The ore bodies that resulted have the shape of the head of a trident in plan view, a trident that points up the slope of the beds and is three-quarters of a mile long. The prongs are represented by gently sloping pipe-shaped ore bodies from 50 to 150 feet in diameter that lie entirely within the Leadville limestone and are made up largely of sphalerite, iron sulphide (pyrite), and iron carbonate (manganosiderite). At the base of the trident, however, where the prongs coalesce, the ore cuts downward into the underlying formations in several steep funnel-shaped chimneys, and here the zinc ore gives way abruptly to copper-silver ore. If the published estimates are correct, the reserves of zinc ore are sufficient to maintain the normal mine output for many years.(12, p. 63)

Other districts where zinc sulphide replacement ore in limestone furnishes a considerable amount of zinc include Austinville, Virginia; Mascot and Ducktown, Tennessee; and Hanover, New Mexico. Zinc occurs in complex ores associated with lead, copper, iron, and other metals in many deposits not worked primarily for zinc.

Canada

Three-fourths of Canada's zinc is mined at Kimberly, British Columbia (see page 296), and nearly all the rest comes from the Flin Flon mine in west-central Manitoba. The metamorphosed pre-Cambrian volcanic rocks in which the Flin Flon ore occurs have been greatly altered near intrusive granite masses (porphyry and granodiorite) and later intensely faulted. Copper, zinc, and iron sulphides, and some gold and silver occur as nearly solid massive ore and also are disseminated in the altered volcanic rocks along the great shear zones formed by the faulting. About 4 ounces of gold, 50 ounces of silver, and 1,500 pounds of copper are produced for each ton of zinc. Reserves are large.(4)

Newfoundland

Nearly all the zinc ore mined in Newfoundland is taken from the Buchans mine in the southwestern part of the island. The ore body was completely hidden by soil, swamp, and vegetation but was

discovered by electrical prospecting methods. It is in a terrain of interbedded pre-Cambrian volcanics and impure sandstones that have been strongly metamorphosed, folded, faulted, and intruded by granite and related rocks (quartz porphyry). Ore bodies are localized at the centers of folds and along sheared intrusive sheets where they cut metamorphosed beds of volcanic ash. The ore comprises zinc, lead, copper, and iron sulphides and barium sulphate; the ore averages about 14 per cent zinc, 6 per cent lead, 1.5 per cent copper and carries a small amount of silver. In 1940 Newfoundland had reserves of more than 4,000,000 tons of ore.(18; 19)

Germany

Much of Germany's zinc is closely associated with lead, and some of its lead-zinc deposits have been noted on page 296. The leading zinc-producing areas in Germany would include the Blei-Scharley district of Upper Silesia, the Rammelsberg district in the Harz Mountains, the Ramsbeck-Ems-Holzappel and Mechernicher-Knotten districts in the Rhineland. The lead-zinc deposits of the Blei-Scharley district in Upper Silesia are found in flat-lying Triassic limestones as replacement deposits, or mantas, which range up to 30 feet in thickness and lie at a depth of 300 to 750 feet. The ore deposits underlie many square miles and average 16 per cent zinc and 4 per cent lead. The reserves are large. It is estimated that there are more than 1,000,000 tons of recoverable zinc and nearly 400,000 tons of recoverable lead in developed ore reserves exclusive of the low-grade ore. The annual production of these Silesian deposits is approximately 57,000 tons of zinc and 21,000 tons of lead.

At the Rammelsberg mine, near Goslar, a new ore body was discovered in the late nineteen-thirties below a deposit that had been mined for more than a hundred years. The ore contains from 18 to 25 per cent zinc, 9 to 12 per cent lead, and an appreciable amount of copper and silver. It is massive sulphide ore that replaced the metamorphosed Devonian sediments. The ore body is at least 3,000 feet long and continues to a depth of about 1,000 feet with a thickness of 15 to 45 feet. There are nearly a million tons of recoverable zinc and 350,000 tons of recoverable lead in the proved ore. The annual production is probably about 17,500 tons of zinc and 20,000 tons of lead. The largest zinc reserves in Germany are found in the Rhineland district at the Meggen mine 55 miles east of Cologne where reserves of nearly 3,000,000 tons of recoverable zinc have been proved in a zinc-iron sulphide ore.

Italy

Zinc is one of the few minerals in which Italy has been self-sufficient; but even in this mineral she has been self-sufficient only by virtue of her suzerainty over the neighboring island of Sardinia. The zinc-lead ores are found in the Arbus area 25 miles north of Iglesias. Sphalerite with some galena is found in veins that cut Paleozoic metamorphic rocks near a granite intrusion. Some of the veins are as much as 60 feet wide, and the ore is found concentrated in shoots from 100 to 600 feet long. The ore averages about 8 per cent zinc, 3 per cent lead, and a small amount of copper. Reserves are large and have been estimated as more than 50,000,000 tons. At Trieste, in northern Italy, an appreciable output is derived from zinc-lead deposits whose ore reserves are estimated at about 1,000,000 tons.(10)

Consumption and Production

From 1935 to 1940, the world's annual output of zinc averaged slightly more than a million and a half tons annually. The United States and Italy are the only major powers that were essentially self-sufficient when the second world war started, but by 1942 the Axis nations controlled resources adequate fully to supply their needs in zinc. The production of zinc during representative years is given in Table XLVII, page 381.

The United States

The United States normally produces and consumes about 500,000 tons of zinc, but during peak wartime production from 50 to 100 per cent more is required. Much of this requirement is obtained by increasing domestic output and the rest by imports chiefly from Canada, Mexico, Newfoundland, Argentina and Peru. Of the 666,000 tons of zinc mined in the United States in 1940, Oklahoma alone produced 162,935 tons, by far the largest amount for any state; altogether, the Tri-State region supplied 35 per cent of the zinc produced in the United States. The second largest producer is New Jersey, with about 90,000 tons of zinc each year; next is Idaho, and most of the 70,000 tons credited to this state in 1940 came from the Coeur d' Alene district where zinc is closely associated with lead. Montana produced 52,587 tons and was the second largest producer in the west. Most of the zinc comes from near Butte, one of the greatest copper districts in the world.

Canada

Canada is one of the world's chief exporters of zinc and normally consumes only 6 to 8 per cent of her production. The Canadian zinc output increased steadily through the nineteen-thirties, and it is probable that Canada is capable of sustaining an output of about 300,000 tons for some years.

Newfoundland

There were no zinc smelters in Newfoundland in 1942, and the entire mine output, some 60,000 metric tons of zinc in ore annually, is exported. The zinc consumption of this thinly populated dominion is negligible.

Mexico

Zinc is a valuable by-product of lead-silver mining in Mexico, and almost all of the 30,000 to 40,000 metric tons produced each year is available for export.

South America

The zinc consumption of all the countries south of the United States, including Mexico, is only 15,000 metric tons a year, a little less than the output of Peru. Until 1940, when a small electrolytic plant was erected in Peru, all South American zinc concentrates were exported, chiefly to Europe. Argentina, Peru, and Bolivia, mining about 35,000, 17,000, and 10,000 tons of zinc respectively, are the only South American countries with a substantial zinc output.

Belgium

Belgium is one of the most famous zinc-smelting regions in the world, although it depends entirely on imported ore. Two hundred and twenty-five thousand metric tons of zinc were smelted in Belgium during 1937. Although 24,000 tons of slab zinc was imported, 151,000 tons was exported, indicating a consumption of approximately 100,000 tons. Belgium's imports of ore and concentrates totaled 618,636 tons and were drawn chiefly from Mexico (174,000), Sweden (74,468), Burma (69,746), Canada (55,397), Yugoslavia (54,823), Australia (52,877), and Italy (31,827).

France

Almost no zinc ore is mined in France. Her zinc smelters and electrolytic plants have a capacity about equal to her normal demand of 90,000 tons per year but usually operate at no more than 60 per cent of capacity. In 1937 Mexico supplied 24 per cent; Spain, 21 per cent; Turkey, 11 per cent; Sweden, 10 per cent; and Tunisia, 5 per cent of the ore imported for refining in France. The imports of zinc metal came chiefly from Belgium and Norway.

Germany

The amount of zinc consumed by Germany mounted steadily from 132,000 metric tons in 1932 to about 320,000 tons in 1940. Her mine production was greater than her smelter capacity until 1939 but was equivalent to nearly two-thirds of her demands. With the capture of the unharmed Polish mines of Upper Silesia in September 1939, the mine production became equal to even her war needs. During the latter nineteen-thirties, her refining capacity increased by 15 to 20 per cent yearly. Throughout this period, however, Germany bought ore in large quantity chiefly from Poland, Mexico, Newfoundland, and Australia, and her net imports of ore were about 100,000 tons annually. It is to be assumed that most of this surplus went into a stockpile as a provision for possible miscarriage of war plans in Poland. The difference between domestic smelter output and consumption was met by imports of metal, chiefly supplied by Poland, Belgium, Norway, and Mexico.

Italy

Zinc is one of the few mineral products exported from Italy. Her mine production was stepped up from 98,000 tons of concentrate (averaging 56.6 per cent zinc) in 1935 to 202,000 tons in 1938. Only 60,000 to 70,000 tons is required to supply her refineries for their production of about 35,000 tons annually, and this amount equals her domestic requirements. Most of her surplus ore was exported to Belgium, Poland, France, and Germany prior to 1940.

Norway

From 15,000 to 18,000 tons of zinc concentrates are mined in north Rana, but this amount accounts for only a small part of Norway's yearly output of 45,000 tons of electrolytic zinc. From 60,000 to 75,000 tons of net ore imports is used to augment the

domestic supply. Most of this foreign ore is re-export material from Belgium and France.

The Soviet Union

The Soviet Union became virtually self-sufficient in zinc about 1936 when its increasing refinery capacity overtook its demand at 64,000 metric tons. Its two largest refineries are modern electrolytic plants at Kemerovo in the Kuznetsk Basin, western Siberia, and at Chelyabinsk in the central Ural Mountains. Together they have a capacity of 90,000 tons annually. Smelters of about 12,000 tons capacity are located in the Ukraine and in western Siberia. Much of the zinc ore must be moved long distances by rail before it is delivered at the refineries. Three-fourths of the zinc-lead ore mined in the Soviet Union comes from the Altai Mountains in south-central Siberia northeast of Lake Balkhash, a region that contains about half the known Soviet reserves. The largest reserve is in the Ridder group of sulphide deposits, where about 15,000,000 tons of commercial ore have been proved. Other less important districts are found in southern Kazakhstan close to Lake Balkhash and the Altai Mountains, in the Karamazar Mountains of central Asia, in the northern Caucasus, and in the Trans-Baikal.(10)

Australia

With a consumption of only 30,000 to 35,000 tons of zinc, and lead-zinc districts that furnish between 150,000 and 200,000 metric tons of zinc in ore during normal years, Australia is one of the premier zinc exporters of the world. The smelter output was about 70,000 tons a year in the late nineteen-thirties, but additional refinery capacity developed after Great Britain became involved in the second world war. Mine production was increased to well over 200,000 tons of zinc in ore, but so many of the smelters usually fed by Australia were cut off by the conflict that available smelting capacity was less than the potential output of the mines. In 1938 about 60 per cent of the ore exported went to Great Britain, 35 per cent to Belgium, and 10 per cent to Germany.

Burma

The Bawdwin lead-zinc mine in northern Burma usually makes about 60,000 tons of zinc concentrate that contains about 58 per cent zinc. The concentrates were shipped to Belgium for refining prior

to 1940, when Great Britain took the output until the Japanese invasion of Burma in 1941.

China

The quantity of zinc mined in China is negligible and her consumption is only 5,000 tons per year.

Japan

At the time Japan entered the second world war, she was consuming about 100,000 tons of zinc per year. About half was supplied by imports of metal, chiefly from Canada, Australia, and the United States, and a little less than half came from zinc refineries in Japan operating largely on imported zinc concentrate. Only a few thousand tons of zinc ore are mined in Japan. The sources of the concentrate imported are not known with certainty, but a substantial amount come from North America.

Political and Commercial Control

The political control and the nationality of commercial control are the same for zinc as for lead. (See page 303.)

National Policies

The national policy of the United States has been almost identical for zinc and lead (see pages 304, 305). When the demand created by the war far exceeded domestic supply, the government-owned Metals Reserve Company was authorized to purchase zinc and zinc concentrates from Mexico, Australia, and other countries whose zinc is normally barred from the United States by high import duties.

Great Britain encouraged her domestic smelting industry in the years preceding the second world war by a tax on non-British zinc that amounted to about 10 per cent. In spite of the disparity in bulk between zinc metal and concentrates and the acute need for ships after 1939, Great Britain increased its smelting capacity and imported more ore than in prewar days. The desire for sulphuric acid, a by-product of zinc refining, was one of the strongest arguments in favor of this course of action. However, the zinc refinery capacity of Australia and Canada was also built up, and shipments of zinc metal to the United Kingdom rose sharply.

Belgium has been an important zinc-smelting country for many decades. Her ability to continue as one of the world's important

sources of the metal long after she became entirely dependent on imported ores is due to the low cost of production. This low production cost has been maintained only with the government's co-operation; if forced to pay high wages, high duties, and large taxes, Belgian smelters would soon stand idle.

After Hitler came to power and the nation committed itself to building a Greater Germany, the Third Reich increased mine output, pushed exploration of new deposits, got information on the producing areas in neighboring countries, built up new smelters and electrolytic refineries, and enlarged those already working. A stockpile of zinc ore was accumulated but proved unnecessary when the Silesian mines in Poland were returned to Germany almost undamaged and in far better condition than when their German owners had grudgingly relinquished them to Poland twenty years earlier.

Italy subsidized her domestic electrolytic zinc plants by placing prohibitive tariffs on foreign zinc and thus guaranteed herself an adequate domestic supply. The zinc mines were stimulated to an uneconomic overproduction by an export premium on zinc concentrates. This subsidy was designed to draw out a large enough tonnage to provide sufficient by-product lead to satisfy Italian needs.

The Soviet Union displayed realistic forethought in building up new zinc refineries far back from its frontiers. By the time Germany attacked in 1941, the Soviets' zinc mines, smelters, and electrolytic plants had been integrated into a safe and effective industry fully capable of supplying her increased needs during the war.

The Japanese government clamped its Military Secrets law on all Japanese sources of information in 1937, but it was evident that Japan had increased its purchases of metals, minerals, and mining equipment and was enlarging its smelting capacity. The move into Burma after the successful invasion of the Netherlands East Indies gave Japan possession of the Bawdwin mine and assured adequate supplies of zinc as well as lead and more than sufficient tin for its needs.

(For references on zinc, see references on lead and zinc, page 365.)

CHAPTER 19

Tin

Properties and Uses

TIN is one of the most important industrial metals of the United States and one for which we depend wholly on outside sources. Tin owes much of its usefulness to its low melting point (232 degrees C.), its nontoxic character, its malleability, and its resistance to corrosion. Molten tin readily adheres to other metals, and since early times it has been used for lining or "tinning" copper utensils by the simple method of pouring a small quantity of molten tin into them and then pouring it out again. Tin plate is made by dipping thin sheets of mild steel into a bath of molten tin.

By far the greatest single use of tin is for coating sheet steel to be used in the lowly but essential tin can, that all-important part of the "American Way of Life." Fifty-three per cent of the primary tin that is consumed in the United States ordinarily goes into the manufacture of tin plate; since the metal thus used was seldom recovered, this industry depended entirely on primary tin. If we include the scrap tin used in the United States as well as the primary tin, we find that tin plate still accounts for 43.5 per cent of the tin consumed. The second largest use is in solder, a lead-tin alloy. Solder is one of our most important industrial metals and consumes 23 per cent of the tin used. It is also the largest single source of scrap; about 40 per cent of the solder produced represents reuse of tin. Babbitt or bearing metal is widely used for bearings in rolling stock and machines. It contains about 85 per cent tin, 10 per cent antimony, and 5 per cent copper. Of equal importance is the use of tin in bronze, a copper-tin alloy that contains from 4 to 25 per cent tin. Bronze is indispensable in the manufacture of strong, easily machined noncorroding parts and has innumerable uses in machinery. Bronze and solder each account for about 7.5 per cent of the tin used in the United States. Several thousand tons of tin are used in the packaging industries; collapsible tubes take

about 4 per cent and tin foil about 1.5 per cent of the total tin. Another 1.5 per cent goes into chemicals other than tin oxide, and a similar percentage enters tin tubing, type metal, and tin foil.

Substitutes

There are no thoroughly satisfactory substitutes for bronze, babbitt, and solder, alloys that required 37 per cent of the total tin produced in the United States in 1937. The use of cadmium and silver solders may be extended but will normally replace only a small amount of lead-tin solder. Various types of lead alloys containing one or more of the elements copper, barium, calcium, caesium, and silver have been substituted for babbitt with some degree of success. Aluminum brass and Monel metal may be substituted for bronze in many of its uses, but these substitutes are definitely less satisfactory than the bronze they replace. Both lead foil and aluminum foil may be substituted for tin foil in certain uses, but neither can be used for food products, as poisonous contamination results. Cellophane and paper are satisfactory substitutes for tin foil in much of our food packaging, however. Glass, waterproof paper, and plastics are the best substitutes for tin plate thus far discovered. All three normally compete at a disadvantage where transportation is an important factor.

Tin has almost no direct military use in armament such as characterizes many of the other strategic minerals. Tinned foods are an essential part of an army's supplies, and solder, bronze, and bearing metal enter into innumerable items of both offensive and defensive material.

Technology

The tin oxide, cassiterite, is the most important ore of tin. It is a heavy, insoluble mineral that lacks the metallic luster of many ores and is known commonly as tinstone. The pure mineral contains 78.8 per cent tin. About 70 per cent of the tin produced annually comes from dredges and placer operations, and about 30 per cent from mines. Its high specific gravity makes it easily possible to wash it clean from the light gravel or country rock with which it is associated. All the tinstone placed on the market is concentrated in some form of washing plant or gravity mill. A large amount of tin is washed from placer deposits by hand, using crude devices that are almost identical with those that were described by Agricola more than four hundred years ago. (See Figure 36.)

A—Box. B—Perforated plate. C—Trough. D—Cross-boards. E—Pool.
F—Launder. G—Shovel. H—Rake.

Fig. 36. Placer mining in the sixteenth century. From Agricola's De Re Metallica, Hoover Translation, 1910.

Other methods are required to win the tinstone from the bottom of deep water-covered gravels, however.

Probably the most efficient type of concentrating plant ever devised is the dredge. A modern gold dredge can excavate gravel 75 feet below water level, raise it to the surface, sort out as little as .002 ounces of gold per ton, stack the gravel, and operate at a profit! This ratio of concentration is about 1 to 15,000,000, but even tin dredges with a ratio of one to a few thousand far surpass any land concentration mills treating minerals of comparable value.

As shown in Figure 37, a dredge consists of a shallow-draft flat-bottomed hull or boat which carries the motors and concentrating machinery. At the stern is a huge, heavy, vertical "pin" that extends to the bottom of the pond and about which the boat pivots as it gnaws its crescent-shaped bites into the gravel bank. (See Figure 38.)

The basic elements of a dredge are: 1) an endless chain of buckets for digging gravel; 2) a rotating cylindrical sorting sieve known as a trommel into which the buckets dump the gravel; 3) the "tables" over which small-sized material from the trommel is washed and where the heavy gold or tinstone is saved; 4) the stacker, an endless belt that conveys the coarse material from the trommel to the rear of the dredge and drops it in a neat windrow back of the pond. Cables and power winches raise and lower the bucket chain, stacker, and pin as required by the work, and a small crew can easily operate a dredge handling 15,000 tons of gravel a day. The dredge is held against the bank and made to swing from side to side by means of cables which pass through a winch in the bow and are anchored firmly to buried timbers or "deadmen" in the bank. The tables, which are the heart of the whole system, are smooth, slanting, linoleum-covered platforms on which narrow slats or "riffles" are fastened. The light sand and gravel wash over the riffles, while the particles of tinstone or gold, too heavy to hurdle the obstructions, accumulate against the riffles. On some dredges the tables are jerked back and forth by a small eccentric to facilitate the separation of the minerals, and in many tin and tungsten dredges the tables are supplemented by jigs, another type of gravity concentration apparatus.

A dredge can profitably work tin-bearing gravels even though they contain as little as six ounces of tinstone per ton, but more commonly the placers have from 0.5 to 2.0 pounds of ore per ton of gravel. In contrast, much of the ore mined from tin veins contains

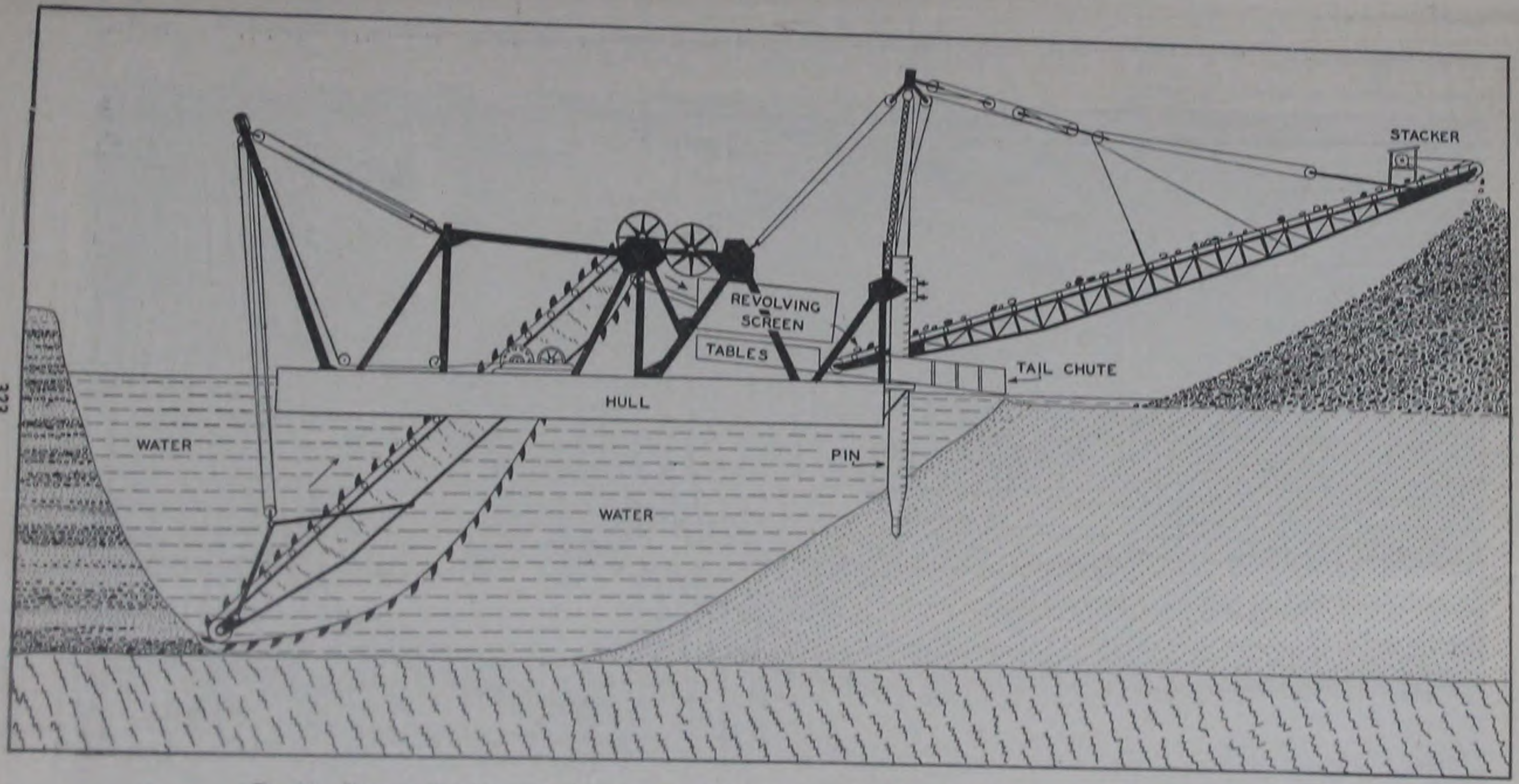
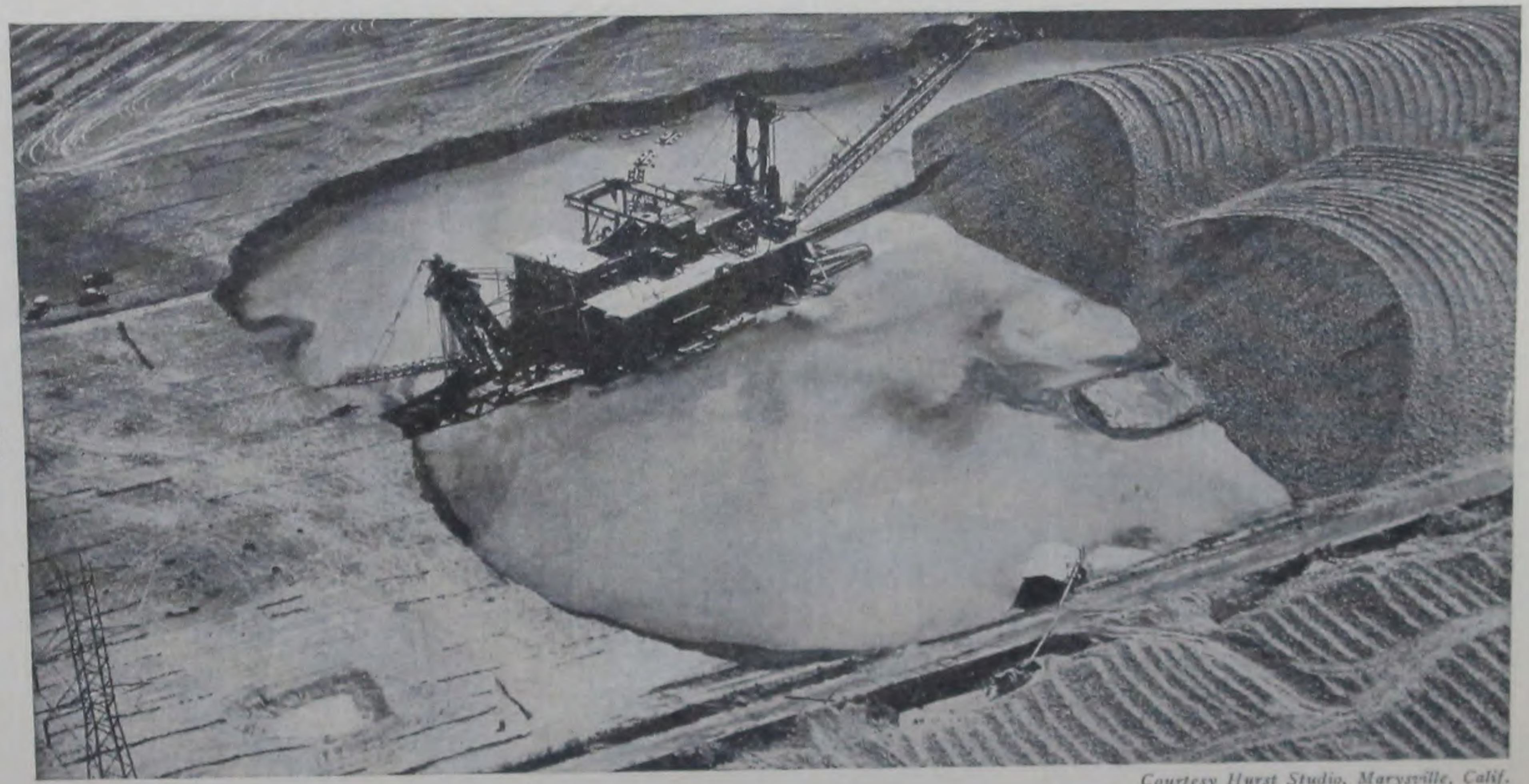


Fig. 37. Diagram showing main elements in a modern dredge. Based on drawings of Yuba Manufacturing Co.



Courtesy Hurst Studio, Marysville, Calif.

Fig. 38. A gold dredge at Hammonton, California. A modern dredge of this type can handle 15,000 tons of gravel a day and may cost a half million dollars.

from 2 to 8 per cent of tin and so is about 80 times as rich as a placer gravel.

Cassiterite is easily reduced to metallic tin in either a blast furnace or a reverberatory furnace. Unfortunately tin readily unites with fluxes and a substantial amount enters the slag. These "first-run" slags have to be resmelted in a carefully controlled furnace in order to reduce the loss to approximately 1 per cent. Tin can be purified by carefully manipulating a bath of molten tin so as to oxidize only the impurities, which accumulate at the surface as oxide dross that can readily be skimmed off.

Geology

The two ore minerals of tin, cassiterite, an oxide, and stannite, a copper-iron-tin sulphide, are found in veins closely associated with granite. Both stannite and cassiterite are resistant to weathering and accumulate as residual deposits at the outcrops of veins and in placers derived from them. Tin is not uncommon in copper and tungsten veins, especially in those of Hercynian age. Most primary tin deposits show evidence that high temperature and great pressure prevailed while they were forming. Such conditions are most likely to be present far below the surface near molten intrusive rocks. In harmony with this genesis, the prospector finds tin deposits in regions where erosion has gone deep and exposed granite bodies. He looks in vain for ore in lava-covered country. It has not yet been possible to find diagnostic features that will allow a geologist to distinguish between granites that have exhaled tin-bearing fluids to form ore deposits and those that were barren of the metal throughout their history. Exploration indicates that except in the extreme north and south the granites of North America were practically devoid of this metal. All other continents are far more fortunate in possessing tin than is North America, but the world's tin is largely concentrated in two areas, a narrow belt that extends southeast from Malaya into the Netherlands East Indies and another belt that runs southeast through the high Andes Mountains of Bolivia and Peru. (See Figure 40.)

Tin Deposits of the World

The Malayan tin belt

British Malaya commonly produces nearly half the world's tin. The world's most productive tin-bearing area extends southward a

thousand miles from Rangoon through the Malay Peninsula to the Dutch East Indies. The primary deposits throughout this belt are veins, pipe-shaped bodies, and impregnations found at or near the contact of Hercynian granite and Paleozoic limestone. Weathering of these deposits along wide north-south valleys has made ideal conditions for placer operations. The large production of Malaya comes from hundreds of small producers rather than from a few large companies. In 1940 there were only 20 operators that produced more than 1,200 tons of concentrates, and the largest individual output was 4,800 tons of concentrates containing 75.4 per cent metal. Of the 85,384 tons of tin produced, 57,672 tons came from the hundred dredges in operation that year, one of which is shown in Figure 39. Nearly all the remaining tin came from 1,021 gravel mines. Hand labor is extensively used, and 82,527 coolies were employed in the gravel workings in 1940.(14)

Nearly all the production of the Netherlands Indies comes from the islands of Banka, Singkep, and Billiton which lie between Sumatra and the south tip of the Malay Peninsula, the Cassiters of the ancients. The country rock includes highly folded Triassic shales and sandstones. The primary tin ores here, as in Malaya, are found in veins and fracture zones near the contact of granite intrusions. Most of the tin lodes are within granite rather than sedimentary rocks, but production is almost wholly from alluvial deposits. Burma and Siam (Thailand) contain the northward extension of the Malayan tin belt and have been sources of tin for many years. Siam normally produces about 15,000 tons and Burma about 5,000 tons.

Bolivia

Tin is one of Bolivia's most important assets, and the 25,000 to 30,000 tons that she produces annually make up about 80 per cent of her export trade. A mineralized belt about 60 miles wide, which contains tin, silver, and copper veins, extends southeast from Lake Titicaca for more than 500 miles. Tin veins are found close to the edge of many small granite intrusives. They cut the granite and its country rock of Paleozoic sediments and Tertiary volcanic rock. Cassiterite and stannite are associated with quartz, feldspar, mica, wolframite, and sulphides of copper, iron, silver, and arsenic. Most of the mines are at elevations of 12,000 to 15,000 feet above sea level. The veins are narrow and mining costs are high compared with those for placer deposits in the Far East. More than

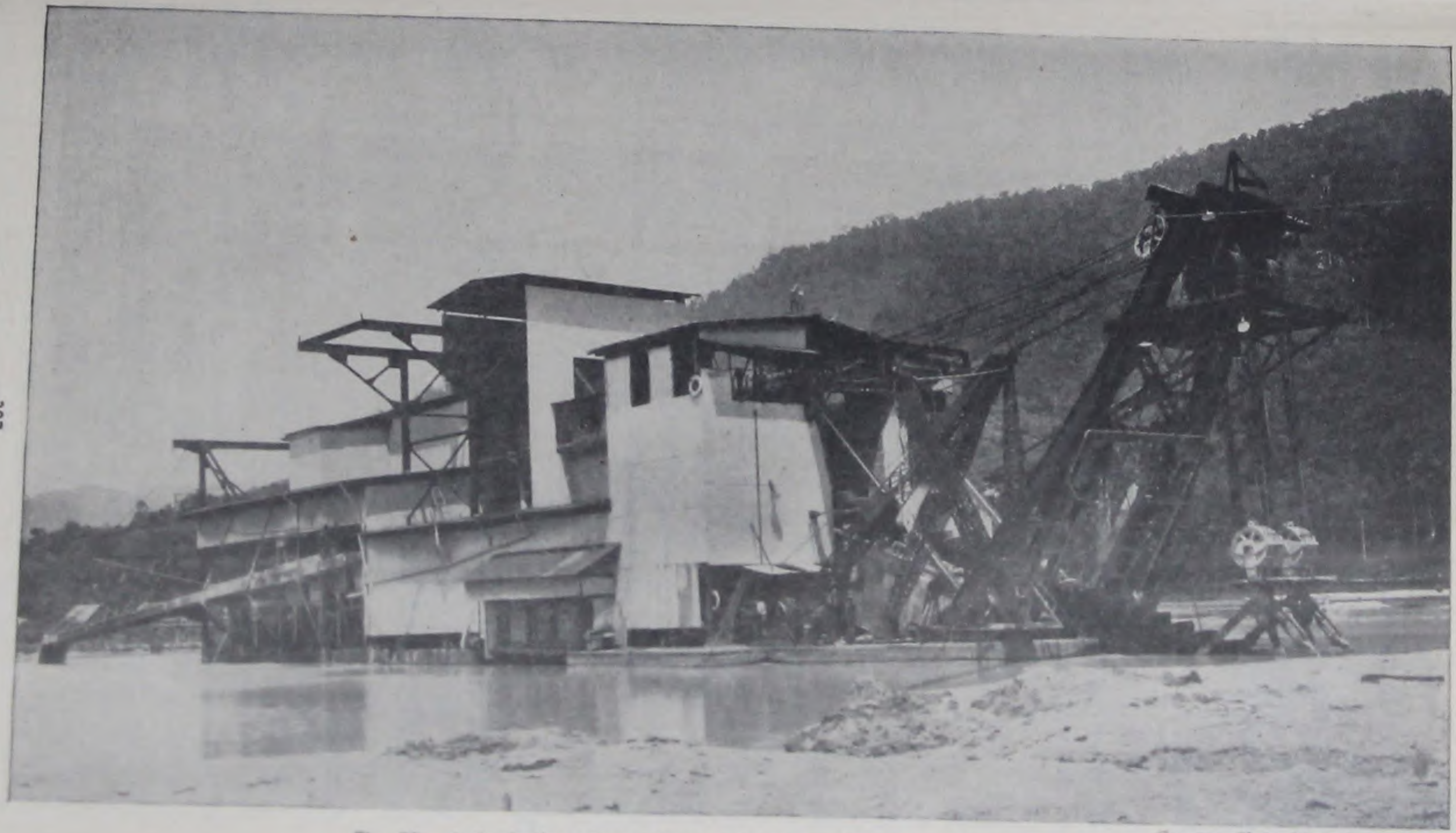


Fig. 39. A tin dredge winning tinstone from a jungle-bordered placer in Malaya. *Courtesy Yuba Manufacturing Co.*

half the tin produced in Bolivia is under the control of *Señor* Simone Patino. The remaining tin comes from many small independent mines worked by Bolivians. Under present mining laws the Banco Minero, a government-financed organization, is the sole buyer for the small mines.

Europe

The famous copper-tin mines of Cornwall, England, were once the most important deposits in the world, but the veins are almost exhausted and England's tin production has been less than 1 per cent of the world total for many years. Some tin has been mined from veins in central Europe, especially in Saxony and Bohemia. The production from tin lodes in northeastern Portugal is comparable with that of Cornwall, but the entire output of Europe is only about 1.5 per cent of the world production.

Africa

Nigeria, the world's fourth largest producer, contributes from 10,000 to 12,000 tons a year to the world output. Tin is obtained entirely from placer deposits in the northeastern part of the colony where shortage of water and inadequate transportation facilities have made development difficult. Some tin is also mined in South Africa.

China

China normally produces about 10,000 tons of tin annually. Nearly all of it comes from southwestern Yunnan and adjacent areas in Kweichow and Hunan.

Australia

Australia was the world's leading tin producer during the eighteen-seventies and contributed nearly one-fourth of the world's output of approximately 40,000 tons at that time. Although its proportion of the world total has declined greatly, the actual tonnage has changed much less and for many years has approximated 3,000 tons per year. The tin comes chiefly from veins in Queensland and New South Wales. Tin lodes also occur in Tasmania to the south.

Consumption and Production

The production during representative years is given in Table XLVIII, page 378, and the consumption of tin is shown in the accompanying table.

TABLE XVI

APPARENT TIN CONSUMPTION OF THE WORLD, 1926–1929 (AVERAGE) AND 1936–1940, BY COUNTRIES (16 p., 685).
(In long tons)

Country	*1926–1929 (average)*	*1936*	*1937*	*1940*
Belgium	1,231	1,336	1,520	900
Canada	2,346	2,164	2,625	3,000
Czechoslovakia	1,513	1,684	1,731	
France	10,260	9,748	9,175	6,000
Germany	12,444	9,164	12,368	10,000
India	2,704	2,293	2,595	3,500
Italy	4,268	3,928	3,601	4,000
Japan	4,506	6,403	8,190	12,500
Netherlands	980	1,284	1,470	1,000
Poland	589	1,322	1,272	
Soviet Union	3,791	9,664	25,125	8,000
Spain	1,565	661	942	
Sweden	1,373	1,692	1,889	1,500
Switzerland	1,742	1,109	1,100	800
United Kingdom	21,988	21,860	25,971	32,000
United States	76,539	73,039	86,663	76,000
Other Countries	15,036	12,549	12,863	
Total	162,875	159,900	199,100	169,500

Table XVI shows that the United States normally consumes a little less than half of the world's new tin, the United Kingdom a little less than a fifth, and Germany and France about a fourteenth. None of these four major consumers produces more than a fraction of its requirements from domestic ore. The United Kingdom, with a production of nearly 2,000 tons a year, is the only one whose output is appreciable, but this tonnage is only 7 per cent of her annual requirements.

Commercial Control

The Malayan output has been controlled jointly by the Chinese and British in nearly equal proportions. British subjects control most of the production in Siam and all the production in Burma, Nigeria, Union of South Africa, and Portugal; thus approximately 44 per cent of the world's tin production in 1939 was in British

hands. Before the Japanese conquest, the Chinese controlled all the production in China as well as that part of the production of Siam and the Malay States not dominated by British capital. Dutch capital controlled all the production of the Netherlands East Indies, a little more than 20 per cent of the total. More than half of the tin produced in Bolivia belongs to Patino Mines, controlled by the Bolivian *Señor* Simone Patino, but 30 per cent of the capital invested is American. British, French, Argentine, Chilean, American, and Bolivian capital participates in the tin produced outside the Patino group. A list of tin-mining companies giving the principal mines, the company headquarters, and the commercial control was published in 1939.(6)

For many years the price of tin has been determined in large part by an international tin agreement or cartel. The entire output of Malaya, the Netherlands East Indies, Bolivia, Nigeria, Siam, the Belgian Congo, and Indo China is fixed by the cartel. This group produced 209,300 tons out of a total of 237,600 tons in 1940. The nonparticipating countries operating with no restrictions produce less than an eighth of the total. In most years, restricting countries have allocated quotas to the operating mines that were well below their capacity. This procedure was essential to maintain a price of 45 to 50 cents per pound.

The tin cartel was organized as the International Tin Committee, March 1, 1931, and at that time included British Malaya, Bolivia, Netherlands Indies, and Nigeria. It was some time before the necessary legislation was passed in each country that allowed the government to assign definite quotas to the various producers. It was not until the latter part of 1932 that the quota plan became effective and tin stocks began to shrink materially. The average price of tin in 1932 was only 22 cents per pound, but in 1933 the price averaged 39 cents and was held at approximately 50 cents per pound for the ensuing decade. The international tin cartel was a producers' group and resentment was aroused in the United States because of the failure to include any representative of the greatest consuming country in the world on the International Tin Committee. The rapid rise in price greatly stimulated research in American packaging industries in an effort to find satisfactory substitutes. Although the tin consumption of the United States did not decrease materially, the substitution of cellophane, cardboard, aluminum foil, and aluminum tubes for tin reduced the potential demand by a substantial amount and also placed the country in a far better position to

stand the drastic curtailment of supplies consequent on our entry into the second world war.

National Policies

In 1940, for the first time, most of the tin cartel countries were unable to produce the quota allowed them. This failure was in large part due to the heavy buying of the United States government-owned Metals Reserve Company which was authorized to buy 75,000 tons of tin for a strategic minerals stockpile. The purchases were made at 50 cents per pound and stabilized the price at this figure. The government constructed a tin smelter near Galveston, Texas, and the Metals Reserve Company contracted with the Bolivian government for a yearly supply of 18,000 tons of tin ore. This amount of tin should be sufficient to meet military needs. By October of 1941, shortly before tin supplies from the Far East were cut off by the Japanese, published stocks in the United States were 113,000 tons, a substantial reserve that eased transition to wartime economy.

With three-fourths of the world's tin supply in enemy hands in 1942, the United Nations were forced to curtail consumption of tin in a drastic way. The intense research for tin substitutes that had been carried on for years in the United States pointed the way to balancing the greatly curtailed supply with the requirements deemed most essential. One of the most effective measures employed was the shift from hot-dipped tin plate to electrolytic tin plate, a shift accomplished by virtually all the major tin-plate manufacturers of the United States before the close of 1942. An electrolytic tin coating one-third the thickness of the coating formed by the hot-dip process gives the same degree of protection. Substitution of tinless solders made a further large saving, and employment of substitutes was made compulsory in hundreds of articles formerly consuming thousands of tons of tin each year.

Outside the United States and Great Britain tin is used largely for bronze, solder, and similar alloys, rather than tin plate. It has been the policy of industrial nations of Europe to assure themselves of adequate supplies by accumulating a stockpile of a few tens of thousands of tons. The actual amount that Germany, Japan, Italy, and Russia had on hand at the beginning of the second world war is uncertain, but with the experience of the first world war in mind it is probable that the Axis nations obtained a supply sufficient to last them for several years before embarking on hostilities.

The desire to cripple the economy of the United Nations no less than the need to acquire the tin, rubber, oil, cinchona, and other vital war materials of the East Indies motivated the Japanese drive into this rich island empire of the Netherlands and the invasion of Malaya.

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CHAPTER 20

Mercury

Properties and Uses

MERCURY is the only common metal that is liquid at ordinary temperatures. It is resistant to corrosion, is a fair conductor of electricity and heat, melts at minus 39 degrees C., boils at 357 degrees C., and has a density of 13.6. Its uses as a metal are almost entirely dependent on these properties, but almost 70 per cent of the mercury produced enters into chemical compounds. Power is generated more cheaply and efficiently in a two-stage process that uses both mercury vapor and steam than is possible in the ordinary steam boiler plant. Mercury boilers are economical only in large installations, however; the smallest in the United States have a 10,000 kilowatt capacity and require about 65 tons of metallic mercury. Such mercury can be reused indefinitely with no loss. Metallic mercury dissolves gold and silver and is much used to recover the precious metals where they occur in finely divided form. Nearly two-thirds of the gold produced in the United States is amalgamated with mercury at one stage of the recovery process. Perhaps the most vital uses to which mercury is put are in various types of electrical and scientific apparatus. Mercury is the heart of various control devices that are used for regulating traffic lights, electric signs, and industrial instruments of various sorts. It is also used in mercury vapor lamps, in rectifiers, and in several types of electrolytic cells in the chemical industry.

Many mercury compounds are relatively insoluble and strongly colored; the more soluble forms are antiseptic and many of them have great therapeutic value. The mercury used as a metal has an extremely high secondary recovery, but nearly all that used in chemical compounds is completely expended. The relatively insoluble and poisonous character of mercuric oxide makes this compound ideally suited for marine antifouling paints for the bottoms of ships. Mercury sulphide is a brilliant red color and was the

original Chinese vermilion. It is an excellent pigment but is too expensive to find extensive use.

More mercury is consumed in drugs, chemicals, and disinfectants than in any other use, but almost as much enters fulminate of mercury, the best detonator known for ammunition and dynamite. Together they normally account for about half the mercury required. Mercuric nitrate was used formerly in the manufacture of felt, but in 1941 felt manufacturers agreed to dispense with this chemical because of the deleterious effect it had on the health of the workers. This decision released about 5 per cerrt of the mercury consumed in the United States for other uses.

Substitutes

There are no satisfactory substitutes for metallic mercury in many of its uses. Mercurial compounds are more satisfactory than any others in a number of fields, but various organic compounds are being substituted in increasing quantities each year. Lead azide is replacing fulminate of mercury to a large extent in the manufacture of ammunition. Some antifouling paints contain no mercury, but the United States navy definitely prefers the mercuric type.

Technology

Nearly all the mercury mined occurs in the form of a sulphide, chiefly the red mineral, cinnabar, but a small amount of metallic mercury is associated with some ores, especially in the oxidized zone. The extraction of mercury from cinnabar is extremely simple in principle. The ore is roasted at a low temperature to remove the sulphur and then raised to a higher temperature to volatilize the mercury. The mercury vapor is passed through water-cooled condensers, liquefied, and stored in iron flasks that hold 76 pounds of mercury each. A metric ton of mercury is equivalent to 29.03 of these mine units. It is almost universal practice for the miner to reduce his ore to metallic mercury at the mine. The small, inefficient home-made mercury stills operated at many properties result in the loss of 15 to 20 per cent of the mercury, and the leaking mercury vapor causes many cases of chronic mercury poisoning among the workers in the neighborhood. Most of the mercury ore mined ranges between 0.5 per cent and 2 per cent in mercury, but in times of high prices, lower-grade ores can be successfully treated.

The price of mercury is based on the 76-pound flask as a unit and in peace time usually ranges between $75 and $100 a flask.

During a war, because of the large demand for mercury in drugs, antifouling paint, and detonators, the price generally ranges from $150 to $200 per flask.

Geology

All primary ores of mercury consist of mercuric sulphide and are of magmatic origin. Cinnabar veins are typical epithermal deposits, and this volatile metal is rare in ores that formed at considerable depth near hot crystallizing intrusions. Its habitat is at a shallow depth in regions of recent volcanic activity where faulting has been active and erosion has not cut too deep. Some mercury ores have replaced limestones (as at Terlingua, Texas), but most mercury deposits of the world occur in complex fractures whose continuation both on the surface and in depth are difficult to predict in advance of exploration. Mercury, like antimony, is almost confined to a few mineralogenetic provinces in the Tertiary mountain belts of the world. The deposits in the three great producing areas, northern Italy, Spain, and California, are all of Tertiary or Quaternary age. The important districts of the world are shown in Figure 40.

Mercury Resources, Production, and Consumption of the World

The United States

Although quicksilver is produced in Alaska, Arizona, Arkansas, California, Oregon, Utah, Idaho, Texas, Nevada, and Washington, California produces about half of the United States total, Oregon about a fourth, and Nevada about a sixth. Nearly all the California production comes from the western part of the state south of San Francisco. Recent work by E. B. Eckel of the United States Geological Survey suggests that most of the mercury ores of California are closely related to the thoroughly broken ground adjacent to great thrust faults. These master fractures extend for many miles, but the individual ore shoots related to them are likely to be pockety, a feature characteristic of the vast majority of mercury deposits elsewhere.(1)

Mercury has been known in California since 1824, but production was negligible until 1860. Rich ore and the rapid exploitation of the gold deposits of California with the consequent demand for "quicksilver" by gold metallurgists encouraged the maximum rate of exploitation of the local mercury deposits. Within a year

California was producing more than any foreign country. With the exception of a few years of low activity, California maintained leadership until 1882 when Spain again took first place. At the peak, in 1877, California produced nearly 80,000 flasks of mercury, more than twice as much as Spain, her closest competitor.(3) However, as the high-grade ore became exhausted, mining became less and less profitable and production decreased rapidly. The United States sank to third place in 1908, and except for a brief period during the first world war she has remained in this place ever since, reaching an all-time low with an output of about 150 tons in 1920. Our production has been exceedingly erratic ever since, ranging from a low point of 333 tons in 1933 to 1,802 tons in 1940. The 1940 production was slightly more than double that of the preceding year, reflecting the natural response of a marginal industry to a 200 per cent increase in the selling price of its product.

The war demand for mercury led to prospecting and intensive geological work, and several new districts were discovered in the western states in 1939 and 1940. The aggregate production of all the districts was sufficient to more than satisfy our domestic demand for the first time since 1917, and exports once more exceeded imports. Our normal consumption is approximately 25,000 flasks, or slightly more than 900 metric tons. The deposits opened up during the second world war should be enough to supply domestic requirements for several years, if a high price is maintained for mercury. However, many of the producers will be unable to operate if mercury again sells for a dollar a pound. It is, of course, evident that conditions existing during a war cause rapid depletion of the meager resources possessed by the United States. It will probably be necessary to accumulate a substantial stockpile of mercury before the country can undertake a third world war.

Canada

Mercury deposits have been discovered in British Columbia that promise to contribute materially to the world's output. The deposit at Pinchi Lake began producing mercury in June 1940 and was probably the main source of this metal in the British Empire within a few months. Only the figures for the first month's operation are available; they suggest a production of about 5,000 flasks per year, equivalent to about 350 metric tons.(5)

Mexico

Several mercury deposits are known in Mexico, the most important being in the states of San Luis Potosi and in Guerrero in southern Mexico. The ores of the Huitzuco deposits in Guerrero apparently occur in the vents of extinct hot springs, and the cinnabar lies in a rubble of boulders and mud.(13)

Most of the mercury produced in Mexico comes from small properties operating on only a shoestring of capital. The lack of money prevented installation of new equipment and an expansion in production in response to the sharp increase of price in the fall of 1939. At many properties the crude apparatus used for refining lost as much as 50 per cent of the mercury, and, as a result, most of the miners suffered from chronic poisoning. However, it is probable that the Mexican government will gradually improve the condition of the miners and the industry. The aggregate tonnage in the many small deposits may add up to a substantial reserve.

South America

Scattered mercury deposits are known in Colombia, Peru, and Bolivia, and for a time the Huan Cavelica district in Peru was one of the most important sources of mercury in the world. Production from these countries, however, has been negligible for many years.

Italy

Italy is the world's largest producer of mercury, and substantially all of her ore is obtained from two districts, Monte Amiata and Idria. Monte Amiata is in Tuscany about halfway between Rome and Florence. Mercury is found here in fractured Mesozoic and Eocene sediments beneath Tertiary lavas. Although the deposits have been worked for several years, apparently a substantial amount of ore is still unmined. Monte Amiata was the only Italian source of mercury until after the Versailles treaty when Idria was acquired. The Idria district has also been worked for a long time but it was rejuvenated by new discoveries that resulted from extensive geologic work done at the end of the first world war when it was believed that the deposits were nearly exhausted. The Idria deposits are about 28 miles north of Trieste in territory that belonged to Austria-Hungary in 1914. Here, as in California, the ore is apparently related to the fracturing that occurred near a regional fault of large displacement. Beds of Middle Carboniferous age have been thrust

over Triassic limestones, and the ore occurs in the much-broken footwall limestones below the fault in the more permeable parts of the fracture zone.

Italy's output during the latter nineteen-thirties was approximately 2,300 metric tons per year. This production could easily be increased, however, and represents a quota agreed on by the Spanish-Italian cartel. For many years the world price has been fixed by this cartel, and it is interesting to note that in 1940 the Italian home price was $53 a flask when the export price was $200 a flask. During the second world war export was forbidden except under special license, and taxes amounting to $100 a flask were included.

Spain

Mercury mining is a state monopoly in Spain, and the world-famous Almaden deposit has been state property for more than 600 years. Although there are many other deposits where cinnabar ores occur, they are all dwarfed by the presence of one of the most remarkable mines in the world, the Almaden mine in south-central Spain, about 120 miles northeast of Seville. This mine has a production reaching back 2,000 years and is still the world's largest producer of mercury. The ore contains from 6 to 8 per cent mercury and the reserves are larger than those of any other known mercury mine. This ore is several times as rich as that of Italy and the United States, where the ore commonly ranges from 0.5 to 1 per cent. Steeply dipping metamorphosed Silurian beds are cut by dikes of Tertiary volcanic rock whose intrusion is probably related to the mercury mineralization. Three ore bodies a thousand feet long have been found. Each has an average width of about 12 feet and has been mined to a depth of more than a thousand feet. As noted under "Italy," the amount of ore raised is determined by conference with the Italian producers.(6; 10; 12)

The Soviet Union

The Nikitovski mine in the Don River basin of the Ukraine has produced mercury for more than 50 years, and new deposits have been discovered in central Asia and in Oirotiya, Siberia. The Soviets' production is not accurately known but is believed to be about 300 tons per year. This tonnage is apparently adequate to supply domestic requirements, as Russia's imports have been negligible for several years.

Germany

Czechoslovakia formerly maintained a small output from a mine at Zips in the eastern part of the country about 120 miles northeast of Budapest. Germany also produces a small amount of mercury from the Pfalz mine in the Rhine palatinate.

China

China was formerly an important producer of mercury, but the industry has been nearly dormant for many years. However, the national government began exploitation of the Kweichow deposits in 1940, and more than a hundred tons of mercury was produced in 1941.

Commercial and Political Control

Because all the Spanish deposits are state owned, political control is absolute. In Italy the deposits are in the hands of private producers but the state participates in the industry and controls production of ore through export licensing. The production of these two countries is pooled in the Spanish-Italian cartel, which controls 65 per cent of the world's production. The mercury mines of the United States are controlled by United States citizens, and the output was 15 to 20 per cent of the world's production during the second world war. Production is almost everywhere controlled by the nationals of the producing countries, thus political and commercial control is identical.

National Policy

The national policies of the leading producing countries have already been suggested in the discussion of Italy, Spain, and the United States. So far as is known, none of the United Nations accumulated a substantial reserve stock of mercury before entering the second world war. However, the Spanish-Italian cartel, Mercurio-Europeo, marketed ore in London until early in 1940 when it withdrew and established its offices in Basel, Switzerland. From that time on the Axis powers took nearly all the mercury produced in Spain and Italy. Japan succeeded in acquiring a substantial surplus stock from Europe before opening war on the United States, but to judge from her profligate use of money in Mexico, where she was able to get "bootleg" mercury and other metals till late in 1941, her stocks were not as large as she had desired.

CHAPTER 21

Antimony

Properties and Uses

ANTIMONY is a brittle, moderately hard metal which melts at 630 degrees C. and boils at 1,440 degrees C. Its chief use is as a hardening agent in lead alloys. The term "hard lead" is a synonym for antimonial lead, which is a lead alloy containing 4 to 12 per cent antimony. Hard lead enters into a wide variety of materials including storage battery plates, electric cable sheaths, lead pipes, sheet lead for lining sulphuric acid vats, and lead foil for collapsible tubes. Bearing metal is an alloy of lead, tin, and antimony containing from 3 to 20 per cent of antimony. Hard lead is also used in making type metal, which commonly contains from 10 to 25 per cent antimony, the composition of the alloy depending upon the use to which the type is put. Britannia metal is a lead-antimony-copper alloy, and pewter is a tin-antimony-lead alloy. Both were formerly used in making low-temperature castings of household ware. Antimony trioxide and antimony trisulphide are used to some extent as white and red pigment. The heavy white fumes of the volatile oxide and sulphide make excellent "chemical smoke" and are much used in warfare. A small amount of the trisulphide is used in the manufacture of safety matches. Antimony also finds a limited use in the rubber industry and in medicine.

Hard lead is extensively used for shrapnel and as cores for steel-jacketed bullets. Antimony sulphide is used in shrapnel shells to produce a chemical smoke and allow the observers to spot the location of the shellburst.

The United States consumed nearly 30,000 tons of antimony in 1940. Of this amount, approximately 10,000 tons was used in the manufacture of storage batteries, and 8,223 tons was used in the chemical industry, chiefly in the production of oxides. As with tin, several thousand tons of antimony enter bearing metal each year.

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Substitutes

Cadmium makes a satisfactory substitute for antimony in bearing metal but is more expensive. The bearing metal substitutes, which were discussed under tin, are equally effective when substituted for antimony. Recently a calcium lead alloy was developed that will substitute for the hard lead battery grids that contain 10 per cent antimony. Apparently from 1 to 4 parts of calcium in the lead are as effective as a hundred parts of antimony.

There is a very high recovery of antimony in most of its peacetime uses. The United States usually fills from 40 to 45 per cent of her needs from antimonial scrap, and it should be possible to increase the percentage appreciably.

Technology

The chief primary ore mineral of antimony is stibnite, the antimony trisulphide, but some antimony is associated with copper, silver, and lead in complex antimonides and sulphantimonides in many ore minerals. Primary antimony minerals break down readily to secondary oxides in the zone of weathering, and a substantial amount of the ore treated belongs to this latter variety. Stibnite is easily fusible, and it is common practice to liquate rich sulphide ore by heating it slowly and drawing off the molten sulphide, which is known as crude antimony. This product is well suited to many chemical uses and is merchantable without further treatment. To produce antimony metal, the sulphide ores are first roasted at a low, carefully controlled temperature to form the oxide. Antimony oxide is then reduced with charcoal in a small reverberatory furnace and the impurities are slagged off, soda ash being used as the flux. It is also possible to produce the metal directly from crude antimony by fusing it with metallic iron. The sulphur unites with the iron to form an iron sulphide dross that floats on the top of the reduced metallic antimony. The amount of antimony contained in the complex lead, silver, and copper sulphantimonide minerals is not large enough to class them as antimony ores, although antimonial bullion may be a valuable by-product from mining these complex ores.

Geology

Stibnite is the primary mineral of all ores mined chiefly for their antimony content, but as noted above, the oxidation of stibnite in

the zone of weathering produces secondary ores of different character. Nearly all stibnite deposits occur in the early Tertiary mountain ranges of the world and show evidence of having formed at relatively shallow depths below the surface. The ore occurs in veins and complex fracture zones and to a lesser extent as replacements of fractured limestones. With only rare exceptions, individual stibnite ore bodies are "pockety" and irregular in grade. Most of the world's antimony comes from many small mines concentrated in antimony districts of considerable extent rather than from a few large deposits. However, in recent years, a relatively extensive disseminated antimony deposit has been discovered in the United States. The major districts of the world are shown in Figure 40.

Antimony Resources of the World

The United States

The complex ores of the Coeur d'Alene district of Idaho yielded 810 short tons of by-product antimony in 1940. Similar ores are mined in many other western districts, but the antimony in most of them is not recovered. There are several small antimony mines in the western United States and one or two in Alaska, but only one large deposit is known. At the Yellow Pine mine in southern Idaho, reserves of more than 2,500,000 tons of low-grade ore are believed to be present which probably contain 18,000 tons of recoverable antimony. The stibnite occurs in veinlets and disseminated through wide shear zones in a large granite mass (the Idaho quartz monzonite batholith). Most of the antimony is in a northeasterly shear zone which is about 180 feet wide and dips steeply to the east. Much of the ore runs only 1 or 2 per cent antimony, but it can be mined cheaply by open-pit methods. However, it did not begin to produce an appreciable amount until 1942. The antimony ore at the Yellow Pine mine is associated with both gold and tungsten (scheelite). The production figures for antimony and tungsten are not available, but the Yellow Pine mill treated 132,000 tons of ore in 1941.(2; 13)

It seems probable that the amount of antimony obtainable from the Yellow Pine mine and the scattered deposits in California, Arizona, Montana, Oregon, Nevada, and Alaska can produce a substantial proportion of the normal requirements of the United States if a price of 15 to 20 cents per pound is maintained instead of the 12 to 13 cents usually paid.

Mexico

Antimony deposits are widely scattered through Mexico, and in 1940 this country was the world's leading producer. Much of the antimony is recovered as a by-product of the treatment of the complex antimonial lead ores of Monterrey and the antimonial mercury ores of the Huitzuco district of Guerrero. The most important antimony deposits are in San Luis Potosi, Oaxaca, and Sonora, but some antimony is produced in Durango, Zacatecas, and Queretero. Antimony prospects are found also in almost all the other mining states of Mexico. Nearly all the antimony ore is shipped to Laredo, Texas, for conversion to antimony, but the concentrates from the Huitzuco district are treated in the Menardi plant at Los Angeles. It is probable that Mexico will remain one of the world's largest producers of antimony.(5; 12)

South America

Bolivia held the rank of second largest producer of antimony in 1940, a position she held during the first world war as well. The antimony deposits of Bolivia are scattered through many Departments, but the two most important are the districts of Tupiza Potosi and Calapata Oruro. The antimony occurs in narrow irregular quartz veins which cut the black slate belts of the tin zone described on page 326. Since the antimony has some arsenic and copper associated with it, the value of the mine product is materially reduced. Most of the mines are owned locally, and all of the ore is exported. In 1938 nearly three-fourths of the 9,328 tons produced went to Germany by way of Belgium. Although it is the nature of most antimony deposits to be small and unpredictable, the known presence of many antimony veins through the Bolivian mineral zone suggests the presence of others and indicates that substantial reserves probably exist. Bolivia, like Mexico, may be expected to continue as one of the world's important antimony producers. The Bolivian antimony zone extends northward into Peru, but Peruvian output though substantial amounts to less than 1,000 tons per year. Several antimony deposits contribute to this output, and it is possible that further exploration will result in discoveries that can substantially increase the total.(3; 5)

France

France formerly produced several hundred tons of antimony from domestic ores and a much larger quantity from imported ores.

The domestic production, after declining steadily for a decade, ceased in 1934. The smelter production of 1,590 metric tons in 1934 and 1,691 metric tons in 1935 was made up largely of ore imported from Algeria. The antimony deposits that supplied the smelter earlier are 60 miles south of Laval and 150 miles west-southwest of Paris. The antimony occurred in a number of narrow quartz veins from 6 inches to 2.5 feet wide, which cut metamorphic rocks of upper Silurian age. The stibnite is associated with iron, arsenic, and zinc sulphides and a minor amount of gold. Similar deposits are known at Ouche in the highlands of southern France about 150 miles north of Marseilles, but so far as is known, these deposits have not been worked since 1932.(3)

Germany

Until her acquisition of Czechoslovakia, Germany had no deposits of antimony ore and was entirely dependent upon imported antimony. About 80 per cent of her imports came from China and she obtained the remainder from Czechoslovakia. Prior to 1937, her normal consumption of new metal was about 2,500 tons per year. Czechoslovakia produced slightly more antimony than was required to supply her own demands. The Cucma mine in southern Slovakia furnished about 65 per cent, and the remainder was obtained as a by-product from the complex lead-silver-antimony ores near Pribram.(3)

Italy

Italy is the second largest producer of antimony among the industrial nations and probably had an output of about 900 tons in 1940. The ore occurs in veins and irregular masses at the contact of metamorphic rocks and intrusive rocks (porphyries) in the center of Sardinia. Italy's normal consumption of antimony is about 600 tons a year.(14)

Yugoslavia

Although several antimony deposits are known in Yugoslavia, the most important is the Stolica mine a few miles north of Krupanj. This mine has been developed by British capital. Several pipe-shaped bodies of stibnite occur in limestone at its contact with a fine-grained igneous rock (trachite). The ore assays about 17 per cent antimony, and reserves of 20,000 tons had been developed by 1937. The reserves of this mine, together with those of several other antimony deposits in the region to the north of Kopang, should be suffi-

cient to allow a production of several thousand tons annually for many years.(3)

The Soviet Union

Rich bodies of antimony are known in the Raxdolnung Skoa deposits in the Krasnoyarsk district of Siberia, and extensive deposits of low-grade ore are reported to exist in the Kadam Dzhaiskoe districts of central Asia. Many small deposits have been found in central Siberia, the north Caucasus Mountains, Trans-Caucasia, and Kazakhstan. The Soviet Union has been much slower to develop antimony deposits than most of her other metallic resources, and was believed to be largely dependent on imported antimony at the beginning of the second world war. Her imports in 1935 and 1936 were 2,375 tons of metal.

The United Kingdom

Although the United Kingdom has no antimony deposits within its borders, it is second only to the United States in its consumption of the metal. Britain normally takes 6,000 to 7,000 tons a year, but the rearmament program almost doubled the demand. Most of the antimony metal and the crude antimony are imported from China.

Algeria

Algeria has for many years maintained a production of 700 to 1,000 tons. A few small deposits of oxidized antimony ore have been found in limestone beds in northeastern Algeria near Constantine. The reserves are not large, and unless new deposits are discovered soon, the antimony production of Algeria will probably decrease materially in the future.(1)

China

China was the world's premier producer of antimony until the changed conditions resulting from the Japanese invasion began to affect operation. However, 99 per cent of the Chinese antimony mines are in southwest China, territory still held by the Chinese in 1942. The Japanese control of the normal trade routes effectively cut down the Chinese exports. Most of the ore is mined in Hunan near Changsha, but production is also maintained in Yunnan, Kwenchow, Kwantung, Szechwan, and Kwangsi. The deposits in Hunan comprise many small pockets of nearly pure stibnite which

occur as replacements in a dolomitic limestone. Because of the pockety character of the individual deposits, no satisfactory estimate can be made of the Chinese reserves; but the large number of deposits known through an extensive mineralized belt suggest a large reserve tonnage, both discovered and undiscovered. When normal transportation is restored, China will probably resume her position as the world's leading producer of antimony and should maintain it for many years.

Japan

Japan has several small antimony deposits, the chief of which are on the island of Shikoku. In spite of strenuous efforts to increase her antimony production materially, Japan's domestic resources remained entirely inadequate to supply her demands. Antimony smelters were erected during the first world war and for many years Japan smelted several thousand tons of antimony from the ores imported from China. Production from domestic ores averaged less than 50 tons per year during the nineteen-thirties.

Other Countries

No countries, not already discussed, have approached a production of 1,000 tons a year. As shown in the table on page 352, the countries that commonly produce from 100 to 500 tons not already mentioned include Austria, Portugal, Turkey, Morocco, and Australia.

National Policies

As commercial and political control are identical for most of the antimony producers, national policies have been directed toward obtaining revenue from exports in the producing countries and toward encouraging low-cost imports in the consuming nations. As export tariffs are almost invariably higher on metal than on ore, antimony smelters have been established in many of the consuming countries that are deficient in antimony ore. Thus, the United States treats Mexican ore at Laredo, Texas, and at Los Angeles. France operated its smelters on ore from north Africa; Japan smelted Chinese ore; and both Belgium and Germany treated ore from Bolivia, China, and other countries. Germany's acquisition of Yugoslavia, although not especially motivated by a desire for antimony, resulted in gaining control of the Yugoslav mines. The combined production of Yugoslavia, Czechoslovakia, Austria, and

Italy probably amounted to 5,500 tons, enough to take care of the essential war needs of the Axis nations.

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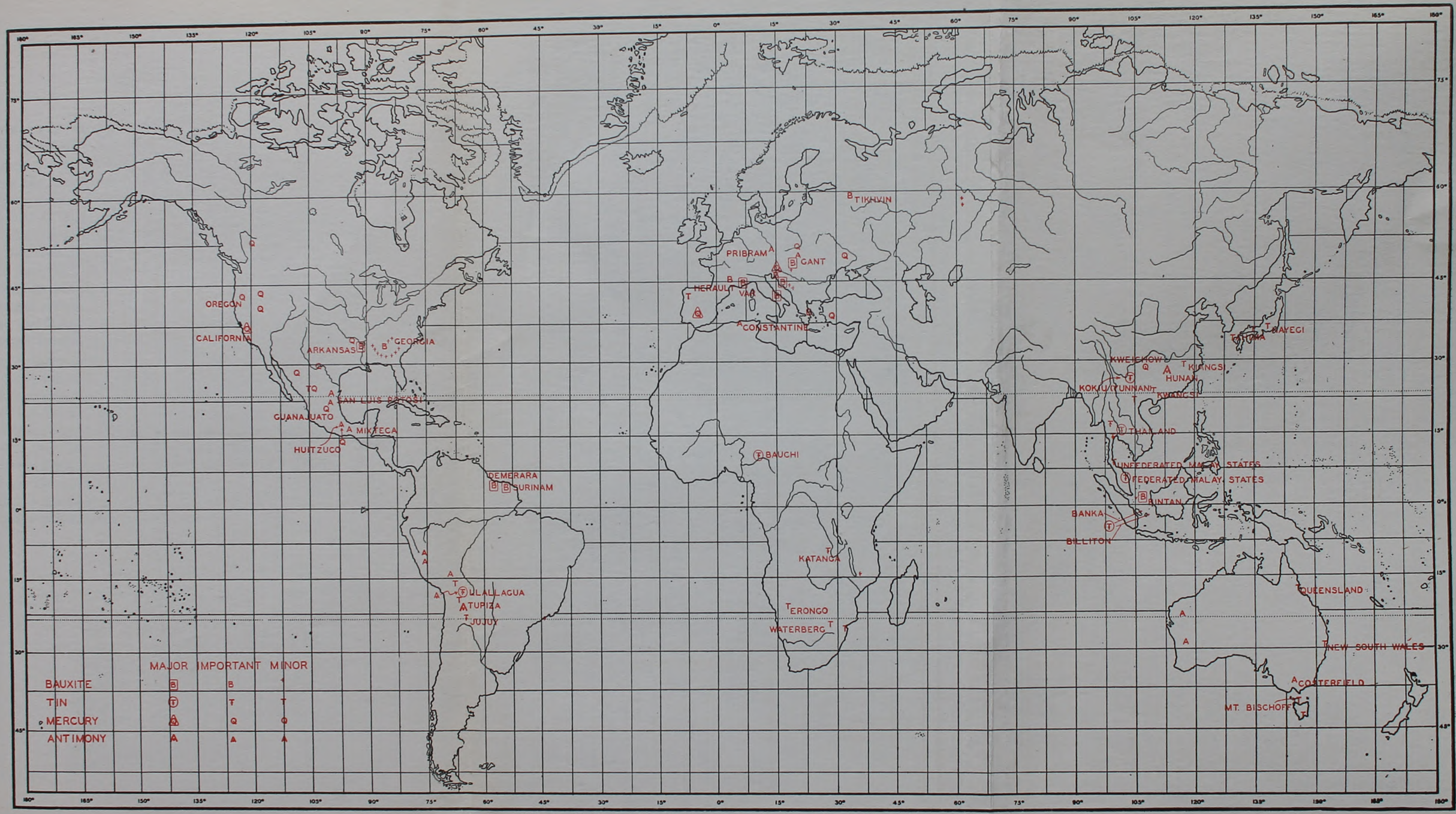

Fig. 40. Distribution of bauxite, tin, mercury, and antimony throughout the world.

APPENDIX

Production Tables

STATISTICS on coal, copper, iron ore, and pig iron prior to 1890 are given for most of the producing countries of the world; mineral production for Germany, Great Britain, and the United States during the nineteenth century are also summarized. The data for these tables all come from Mulhall's *Dictionary of Statistics* (London: G. Rutledge and Son, 1892).

Production figures for the mineral products discussed in this book have been compiled for the representative years, 1929, a peace-time boom year; 1932, a depression year; 1936, the year approximating the average industrial year of the decade 1930–1939; 1937, when industrial activity was strongly influenced by widespread rearmament; and 1940, a year reflecting economic dislocations and demands of actual world-wide war. The statistics have been taken chiefly from volumes of *Minerals Yearbook*, United States Bureau of Mines; but in some of the tables, notably those on iron, steel, and sodium nitrate, data were taken from *The Mineral Industry*, McGraw-Hill Book Company, Inc. Some figures in the *Foreign Minerals Quarterly*, United States Bureau of Mines, conflicted with those in the other two references and were given preference. The numerous estimates for production in 1940 were based on general and specific information. The majority of estimates are those published in either *The Mineral Industry* or the *Minerals Yearbook*, but many of them are merely the author's own guess.

TABLE XVII

MINING IN THE UNITED STATES
(In long tons)

YEAR	TONS				
	Coal	Iron Ore	Copper Ore	Lead Ore	Total
1830	1,300,000	400,000	—	7,000	1,707,000
1840	1,800,000	600,000	—	10,000	2,410,000
1850	8,000,000	1,200,000	5,000	50,000	9,255,000
1860	15,000,000	1,600,000	40,000	80,000	16,720,000
1870	33,000,000	3,200,000	80,000	100,000	36,380,000
1880	70,500,000	8,000,000	120,000	150,000	78,770,000
1889	142,000,000	13,300,000	600,000	250,000	156,150,000
1900	243,414,164*	26,073,725			
1910	445,816,040*	53,267,397			
1920	515,886,000*	67,604,465			

* Metric tons.

TABLE XVIII

VON DECKEN'S AND OFFICIAL TABLES OF MINING IN GERMANY (1850–1888)

YEAR	TONS							
	Coal	Lignite	Iron Ore	Lead Ore	Zinc Ore	Copper Ore	Salt	Total
1850	5,100,000	1,500,000	800,000	170,000	150,000	50,000	300,000	8,070,000
1860	12,300,000	4,400,000	1,400,000	150,000	310,000	90,000	400,000	19,050,000
1870	26,400,000	7,600,000	3,800,000	100,000	370,000	200,000	500,000	38,970,000
1880	47,000,000	12,100,000	7,200,000	130,000	500,000	380,000	670,000	67,980,000
1888	65,400,000	16,600,000	10,700,000	160,000	670,000	530,000	950,000	95,010,000

TABLE XIX

MINING IN GREAT BRITAIN (1780–1888)

YEAR	TONS RAISED						
	Coal	Iron Ore	Copper Ore	Lead Ore	Zinc Ore	Tin Ore	Total
1780	8,500,000	200,000	30,000	40,000	5,000	5,000	8,780,000
1800	10,100,000	500,000	50,000	50,000	5,000	5,000	10,710,000
1820	14,000,000	1,000,000	100,000	60,000	5,000	5,000	15,170,000
1830	16,100,000	1,700,000	150,000	70,000	5,000	5,000	18,080,000
1840	35,000,000	3,500,000	150,000	80,000	10,000	5,000	38,795,000
1850	49,000,000	5,500,000	180,000	80,000	15,000	10,000	54,785,000
1860	80,000,000	8,000,000	240,000	100,000	15,000	10,000	88,285,000
1870	110,000,000	14,400,000	110,000	110,000	15,000	15,000	124,650,000
1880	147,000,000	18,000,000	55,000	90,000	30,000	15,000	165,190,000
1888	170,000,000	14,600,000	20,000	60,000	40,000	15,000	184,735,000

TABLE XX

PRODUCTION OF ALUMINUM DURING REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Canada	36,000(13.3%)	17,800(11.9%)	26,200(7.3%)	41,700(8.7%)	110,000(13.7%)[a]
France	29,100(10.7%)	14,400(9.6%)	29,700(8.3%)	34,500(7.6%)	50,000(6.2%)[a]
Germany	31,500(11.7%)	14,100(9.3%)	97,200(27.1%)	127,200(26.9%)	240,000(29.9%)[a]
Austria	2,700(1.0%)	2,000(1.3%)	3,300(0.9%)	4,400(0.9%)	
Hungary	0	0	800(0.2%)	1,000(0.2%)	2,800(0.3%)[a]
Italy	7,373(2.7%)	13,410(9.0%)	15,900(4.4%)	22,900(4.8%)	40,000(5.0%)[a]
Japan	0	0	7,000(1.9%)	10,000(2.0%)	35,000(4.4%)[a]
Norway	29,142(10.8%)	17,787(11.9%)	15,400(4.3%)	23,000(4.8%)	15,000(1.9%)[a]
Soviet Union	0	900(0.6%)	30,000(8.3%)	37,700(7.8%)	55,000(6.9%)[a]
Spain	0	1,100(0.7%)	600(0.2%)	0	500(0.1%)[a]
Sweden	0	0	1,800(0.5%)	1,800(0.4%)	1,400(0.2%)[a]
Switzerland	20,700(7.7%)	13,820(9.2%)	13,700(3.8%)	25,000(5.2%)	28,000(3.5%)[a]
United Kingdom	10,000(3.7%)	8,825(5.9%)	16,300(4.5%)	19,300(4.0%)	35,000(4.4%)[a]
United States	102,270(37.9%)	47,600(31.5%)	102,000(28.4%)	132,800(27.6%)	187,100(23.3%)
Yugoslavia	0	0	0	200(0.0%)	2,800(0.3%)[a]
World total[b]	270,000	149,700	359,900	481,500	803,000[a]

[a] Estimated.

[b] Several minor producers included in world total not listed in table.

TABLE XXI

PRODUCTION OF ANTIMONY (IN ORE) EXCLUSIVE OF ANTIMONIAL LEAD ORES, DURING REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Algeria	0		214	1.3	983	2.8	778	2.0	750	1.9[e]
Argentina	0		0		0		31	0.1	150	0.3[e]
Australia	26	0.1	61	0.4	143	0.4	460	1.2	250	0.6[e]
Austria	560	1.8	0		100	0.3	200	0.5	150	3.7[e]
Bolivia	3,023	9.6	1,176	6.9	6,040	17.1	6,556	17.2	10,813	27.0
Burma	38	0.1	0		82	0.2	28	0.1	80	2.0[e]
Canada	0		0		0		18	0.1	1,500	3.7[e]
China	22,401	71.0	12,002	70.6	16,348	46.6	14,702	38.5	5,493	13.7
Czechoslovakia	556	1.8	480	2.8	829	2.4	997	2.6	1,200	3.0[e]
Greece	55	0.2	262	1.5	159	1.4	0		0	
Indochina	0		0		38	0.1	5	0.0	9	0.0[e]
Italy	306	1.0	302	1.8	402	1.1	414	1.1	750	1.9[e]
Japan	22	0.1	3	0.0	110	0.3	?		?	
Mexico	3,096	9.8	1,388	8.2	6,719	19.1	9,788	25.6	11,286	28.1
Morocco										
French	0		0		88	0.2	20	0.1	?	
Spanish	180	0.6	121	0.7	12	0.0	158	0.4	?	
Peru	86	0.3	14	0.8	696	1.9	848	2.2	835	2.4
Rhodesia	0		0		68	0.2	64	0.2	60	0.1[e]
Turkey	6	0.0	0		457	1.3	536	1.4	700	1.7[e]
United States	0		304	1.8	630	1.8	1,056	2.8	412	1.3
Yugoslavia	210	0.7	0		1,301	3.7	1,447	3.8	3,500	8.7[e]
World total [w]	31,600		17,000		35,300		38,200		40,000[e]	

[e] Estimated. [w] Several minor producers included in world total not listed in table.

TABLE XXII

PRODUCTION OF ASBESTOS IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Australia	260(0.1%)	132(0.1%)	243(0.1%)	168(0.0%)	?
Canada	277,647(69.3%)	111,562(54.4%)	273,322(54.0%)	371,967(60.8%)	313,504(57.0%)
Cyprus	14,017(3.5%)	1,626(0.8%)	9,659(1.9%)	11,892(1.9%)	8,000(1.5%)[e]
Czechoslovakia	0	0	2,700(0.5%)	2,800(0.5%)[e]	3,000(0.5%)[e]
Finland	1,563(0.4%)	756(0.4%)	3,963(0.8%)	3,330(0.5%)	2,000(0.4%)[e]
France	750(0.2%)	300(0.1%)	405(0.1%)	250(0.0%)	50(0.0%)[e]
India	324(0.1%)	91(0.0%)	57(0.0%)	102(0.0%)	100(0.0%)[e]
Italy	2,847(0.7%)	1,284(0.6%)	6,113(1.2%)	6,393(1.0%)	7,000(1.3%)[e]
Japan	1,000(0.3%)[e]	1,000(0.5%)[e]	1,000(0.2%)[e]	1,000(0.2%)[e]	1,000(0.2%)[e]
Rhodesia	38,677(9.7%)	14,303(7.0%)	51,116(10.2%)	51,722(8.5%)	55,000(10.0%)[e]
Soviet Union	29,520(7.4%)	59,800(29.2%)	125,117(24.8%)	125,000(20.4%)	100,000(18.2%)[e]
Swaziland	0	5(0.0%)	0	0	20,000(3.6%)[e]
Turkey	?	58(0.0%)	119(0.0%)	157(0.0%)	100(0.0%)[e]
Union of South Africa	29,970(7.5%)	10,950(5.3%)	22,894(4.5%)	25,975(4.3%)	22,500(4.1%)[e]
United States	2,862(0.7%)	3,229(1.6%)	10,037(2.0%)	10,958(1.8%)	18,198(3.3%)
World total[w]	400,000[e]	205,100[e]	507,000[e]	612,000[e]	551,000[e]

[e] Estimated. [w] Several minor producers included in world total not listed in table.

TABLE XXIII

PRODUCTION OF BAUXITE (ALUMINUM ORE) DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Australia	0.6(0.0%)	1.1(0.1%)	0.8(0.0%)	7.9(0.2%)	1.0(0.0%)[e]
Brazil	0.0	0.0	7.0(0.2%)	8.8(0.2%)	20.0(0.4%)[e]
France	666.3(30.9%)	404.5(40.4%)	649.5(23.0%)	688.2(18.4%)	700.0(15.1%)[e]
Germany	7.3(0.3%)	1.6(0.2%)	12.4(0.4%)	18.2(0.5%)	20.0(0.4%)[e]
Greece	6.3(0.3%)	0.6(0.1%)	129.9(4.6%)	137.4(3.7%)	50.0(1.0%)[e]
Guiana:					
British	188.1(8.8%)	63.5(6.3%)	172.9(6.1%)	305.5(8.1%)	700.0(15.1%)[e]
Dutch	210.0(9.8%)	126.5(12.7%)	234.8(8.3%)	392.4(10.5%)	615.4(13.3%)
Hungary	389.2(18.2%)	111.6(11.2%)	329.1(11.6%)	532.7(14.3%)	700.0(15.1%)[e]
India	9.2(0.4%)	4.5(0.4%)	3.7(0.1%)	15.4(0.4%)	15.0(0.3%)[e]
Italy	192.8(9.0%)	86.6(8.6%)	262.2(9.3%)	386.5(10.3%)	530.0(11.4%)[e]
Malaya	0.0	0.0	0.0	19.3(0.5%)	63.8(1.4%)
Netherlands Indies	0.0	0.0	133.7(4.7%)	199.0(3.6%)	274.3(5.9%)
Rumania	0.9(0.0%)	0.6(0.1%)	10.8(0.4%)	10.7(0.3%)	40.0(0.9%)[e]
Soviet Union	0.0	37.0(3.7%)	203.2(7.2%)	230.0(6.1%)[e]	300.0(6.5%)[e]
United States	371.6(17.3%)	97.9(9.8%)	386.4(13.7%)	431.9(11.5%)	446.0(9.6%)
Yugoslavia	103.4(4.8%)	67.1(6.7%)	292.2(10.3%)	354.2(9.4%)	150.0(3.2%)[e]
World total[w]	2,149.0	1,001.0	2,829.0	3,746.0	4,627.0[e]

[e] Estimated.

[w] Several minor producers included in world total not listed in table.

TABLE XXIV

PRODUCTION OF COAL IN THE NINETEENTH CENTURY

PERIOD	MILLIONS OF TONS													
	Great Britain	France	Germany	Russia	Belgium	Austria	United States	Spain	Canada	Australia	India	Japan	Various	Total
1801–20	210	18	25	—	8	3	5	—	—	—	—	—	8	277
1821–40	390	41	48	—	47	8	13	—	—	—	—	—	19	566
1841–50	420	41	47	—	51	14	44	—	—	—	—	—	20	637
1851–60	650	69	122	—	82	24	110	1	—	2	3	—	30	1,093
1861–70	970	117	277	3	120	70	260	3	5	7	5	1	35	1,873
1871–80	1,305	170	481	19	153	135	510	6	10	14	8	7	37	2,855
1881–89	1,461	190	662	37	160	184	970	10	17	30	12	12	40	3,785
89 years	5,406	646	1,662	59	621	438	1,912	20	32	53	28	20	189	11,086

TABLE XXV

APPROXIMATE PRODUCTION AND CONSUMPTION IN SEVERAL COUNTRIES AT VARIOUS DATES

COAL PRODUCTION (IN TONS)

Year	Great Britain	France	Germany	United States	Belgium	Austria	Various	The World
1800	10,100,000	800,000	300,000	200,000	—	—	200,000	11,600,000
1820	12,500,000	1,200,000	1,500,000	500,000	1,000,000	—	500,000	17,200,000
1840	30,000,000	3,300,000	3,400,000	1,800,000	3,900,000	400,000	2,000,000	44,800,000
1850	49,000,000	4,400,000	6,700,000	8,000,000	5,800,000	2,000,000	5,500,000	31,400,000
1860	82,000,000	8,300,000	16,700,000	15,200,000	9,600,000	3,500,000	7,000,000	142,300,000
1870	110,000,000	13,300,000	34,000,000	32,900,000	13,700,000	9,500,000	9,000,000	213,400,000
1880	147,000,000	19,400,000	59,100,000	70,500,000	16,900,000	16,100,000	11,000,000	340,000,000
1889	177,000,000	24,600,000	84,900,000	142,000,000	19,800,000	24,000,000	12,700,000	485,000,000

COAL CONSUMPTION (IN TONS)

Year	Great Britain	France	Germany	United States	Belgium	Austria
1830	15,500,000	2,700,000	2,500,000	1,300,000	2,000,000	300,000
1840	29,000,000	4,800,000	3,400,000	1,800,000	3,500,000	400,000
1850	46,000,000	9,300,000	6,000,000	8,000,000	4,500,000	2,000,000
1860	75,000,000	14,300,000	15,000,000	15,500,000	6,100,000	3,700,000
1870	98,000,000	18,800,000	30,000,000	33,000,000	10,500,000	10,000,000
1880	128,000,000	28,800,000	52,000,000	72,000,000	11,500,000	14,500,000
1889	148,000,000	34,600,000	75,000,000	143,000,000	14,300,000	22,000,000

PRODUCTION OF COAL DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country		Years									
		1929	%	1932	%	1936	%	1937	%	1940	%
Australia	B	12,300	0.7	11,343	1.0	14,647	1.0	15,716	1.0	18,000	1.1*
Belgium	B	26,931	1.7	21,424	1.9	27,876	1.9	29,859	1.9	25,643	1.5
Canada	B	12,272	0.9	7,507	0.8	10,308	1.0	11,014	0.9	12,628	0.9
	L	3,599		3,142		3,508		3,352		3,295	
China	B	?		28,000	2.5	27,050	1.9*	27,050	1.8*	30,000	1.7*
Czechoslovakia	B	16,521	2.4	10,961	2.3	12,233	2.0	16,778	2.3	15,000	1.7*
	L	22,560		15,858		15,949		17,895		15,000	
France	B	53,736	3.5	46,266	4.2	45,226	3.2	44,319	2.9	50,000	2.9*
	L	1,187		991		920		1,015			
Germany	B	163,437	22.2	104,741	20.5	146,707	21.2	171,148	23.1	220,000	29.0*
	L	175,177		122,647		160,276		184,790		280,000	
Hungary and Austria	B	826	0.5	895	0.5	827	0.6	917	0.6	12,500	0.7*
	L	6,993		5,931		7,105		8,055			
India	B	22,495	1.4	20,477	1.8	22,974	1.6	25,438	1.7	30,000	1.7*
Japan	B	36,139	2.3	28,100	2.5	45,776	3.2	46,000	3.0*	50,000	2.9*
	L	(0.008)									
Netherlands	B	11,581	0.7	12,756	1.1	12,803	0.9	14,321	0.9	10,000	0.6*
Poland	B	46,236	2.9	28,835	2.5	29,748	2.1	36,218	2.4	15,000	0.9*
	L	(0.074)		(0.033)							
South America	B	2,010	0.1	1,825	0.1	2,901	0.2	3,187	0.2	3,400	0.2*
Soviet Union	B	38,423	2.4	53,600	4.7	126,000	8.7	127,000	8.3	130,000	7.5*
Union of S. Africa	B	13,018	0.8	9,921	0.8	14,842	1.0	15,491	1.0	17,176	1.0
United Kingdom	B	262,046	16.8	212,083	18.8	232,115	16.1	244,268	15.9	240,000	13.9*
United States	A	66,975	35.0	45,228	29.0	49,513	30.6	46,189	29.1	46,706	29.0
	B	485,330		280,963		393,780		401,385		453,245	
World total ▾		1,559,000		1,124,000		1,446,000		1,540,000		1,725,000*	

A Anthracite.
B Bituminous.
L Lignite.
% Percentage of world production.
* Estimated.
▾ Several minor producers included in world total not listed in table.

TABLE XXVII

PRODUCTION OF CRUDE CHROMITE DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Brazil	0.1(0.0%)	0.0	3.9(0.4%)	3.0(0.2%)	4.6(0.4%)
Bulgaria	0.0	0.0	0.3(0.0%)	2.3(0.2%)	?
Cuba	53.8(8.5%)	0.0	71.1(6.7%)	94.6(7.4%)	52.8(4.3%)
Cyprus	2.5(0.4%)	1.0(0.3%)	0.5(0.0%)	1.6(0.1%)	?
Greece	24.2(3.0%)	1.6(0.5%)	47.3(4.4%)	52.6(4.1%)	?
India	50.4(7.9%)	18.2(5.9%)	50.3(4.7%)	63.3(4.9%)	?
Japan	9.2(1.4%)	11.7(3.8%)	39.0(3.7%)	?	?
New Caledonia	52.6(8.3%)	69.4(22.8%)	47.8(4.5%)	48.0(3.8%)	55.8(4.5%)
Philippine Islands	0.0	0.0	11.9(1.1%)	69.9(5.5%)	194.4(15.5%)
Sierra Leone	0.0	0.0	0.0	0.7(0.1%)	10.0(0.8%)*
Rhodesia	265.9(41.8%)	15.7(5.1%)	183.4(17.2%)	275.6(21.5%)	300.0(24.0%)*
Soviet Union	52.9(8.3%)	68.0(22.3%)	217.0(20.3%)	?	?
Turkey	16.2(2.5%)	55.2(18.1%)	163.9(15.3%)	192.5(15.1%)	110.0(8.8%)
Union of South Africa	64.0(10.0%)	19.4(6.4%)	175.7(16.4%)	168.6(13.2%)	163.6(13.1%)
United States	0.3(0.0%)	0.2(0.1%)	0.3(0.0%)	2.4(0.2%)	2.7(0.2%)
Yugoslavia	43.0(6.8%)	43.9(14.4%)	54.0(5.1%)	59.9(4.7%)	50.0(4.0%)*
World total**	635.2	305.0	1,068.0	1,280.0	1,250.0*

* Estimated.
** Several minor producers included in world total not listed in table.

TABLE XXVIII

PRODUCTION OF COPPER DURING REPRESENTATIVE YEARS IN THE NINETEENTH CENTURY

Country	Fine Copper (Tons)				
	1850	1860	1870	1880	1888
Australia	2,400	7,600	9,700	13,100	8,000
Austria, etc.	1,600	1,900	2,000	2,200	2,700
Cape Colony	—	—	1,000	5,000	8,000
Chile	14,300	25,100	30,200	36,800	31,000
Europe, total	25,850	29,140	29,570	49,880	81,200
France	2,300	2,500	4,900	5,100	3,000
Germany	1,650	3,200	6,850	10,140	15,000
Great Britain	11,800	13,540	7,220	3,440	1,500
Japan	3,000	3,000	3,000	5,000	11,000
Russia	6,000	5,500	5,500	6,100	5,000
Spain	200	300	1,100	21,300	53,000
Sweden	2,300	2,200	2,000	1,600	1,000
United States	2,700	5,530	12,650	20,260	103,000
Venezuela	2,000	2,000	3,000	4,000	4,000
Other Countries	2,000	3,000	5,000	8,000	15,800
Total	52,250	75,370	94,120	142,040	262,000

TABLE XXIX

PRODUCTION OF COPPER (IN ORE) DURING REPRESENTATIVE YEARS

(In thousands of metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Australia	13.0	0.7	14.9	1.4	18.9	1.1	19.4	1.3	25.0	0.9*
Belgian Congo	137.0	7.0	54.0	5.2	95.7	5.5	150.6	6.5	156.0	5.9*
Bolivia	7.2	0.4	2.0	0.2	3.2	0.2	3.7	0.2	6.7	0.3
Bulgaria	2.0	0.1	0.5	0.0	0.0		0.0		0.5	0.0*
Burma	?		?		4.1	0.2	3.8	0.2	4.0	1.5*
Canada	112.5	5.8	112.4	10.9	191.0	11.1	240.4	10.3	317.0	12.2*
Chile	320.6	16.4	228.2	22.1	256.2	14.9	413.0	17.8	352.4	13.4
Chosen	0.5	0.0	0.7	0.1	3.6	0.2	5.1	0.2	5.0	0.2*
Cuba	15.0	0.8	6.0	0.6	11.2	0.7	13.2	0.6	10.5	0.4
Cyprus	5.9	0.3	3.3	0.3	16.6	1.0	27.5	1.2	25.0	0.9*
Finland	4.6	0.2	6.6	0.6	11.4	0.7	12.0	0.5	20.0	0.8*
Germany	29.0	1.5	30.7	3.0	26.9	1.6	27.1	1.2	35.0	1.3*
Austria	2.1	0.1	0.2	0.0	0.0		0.0			
India	7.2	0.4	11.4	1.1	9.0	0.5	11.2	0.5	5.0	0.2*
Japan	81.6	4.2	75.4	7.3	82.0	4.8	92.0	3.9*	110.0	4.2*
Mexico	86.6	4.4	35.1	3.4	29.7	1.7	46.1	2.0	37.6	1.4
Newfoundland	0.9	0.0	2.2	0.2	5.3	0.3	8.5	0.4	9.4	0.4
Norway	18.9	1.5	16.9	1.6	22.6	1.3	20.1	0.9	14.0	0.6*
Peru	57.0	2.9	22.9	2.2	33.4	1.9	36.6	1.6	37.7	1.4
Philippine Islands	0.0		0.0		0.0		0.0		9.3	0.4
Portugal	4.0	0.2	2.0	0.2	2.0	0.1	2.0	0.1	5.0	0.2*
Rhodesia	5.9	0.3	88.6	9.6	173.5	10.1	249.8	10.7	365.0	13.9*
South-West Africa	12.6	0.6	2.4	0.2	0		0		1.5	0.1
Soviet Union	26.0	1.3	32.0	3.1	83.0	4.8	94.2	4.1	150.0	5.7*
Spain	63.7	3.3	35.0	3.4	30.0	1.7	28.0	1.2	30.0	1.4*
Sweden	1.1	0.1	4.3	0.4	8.1	0.5	7.2	0.3	10.0	0.4*
Union of South Africa	9.3	0.5	9.4	0.9	9.1	0.5	11.4	0.5	20.0	0.8*
United Kingdom	0.1	0.0	0.1	0.0	0.1	0.0	0.0		0.0*	
United States	905.0	46.4	216.0	20.9	557.6	32.3	763.8	32.8	796.6	30.3
Yugoslavia	15.2	0.8	19.0	1.8	39.6	2.3	42.3	1.8	67.0	1.5*
World total**	1,951.0		1,033.0		1.726.0		2.329.6		2.626.0*	

* Estimated

** Several minor producers included in world total not listed in table

TABLE XXX

SMELTER PRODUCTION OF COPPER DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Australia	11.0	0.6	13.5	1.4	13.5	0.7	17.7	0.8	25.0	1.0*
Belgian Congo	135.5	7.1	54.0	5.7	95.7	5.6	150.6	6.4	156.0	6.1*
Belgium	8.9	0.5	26.9	2.9	58.8	3.4	90.3	3.9	50.0	2.0*
Canada	72.7	3.8	95.7	10.2	173.4	10.1	210.0	9.0	250.0	9.8*
Chile	303.2	16.1	97.5	10.4	244.7	14.2	396.5	16.9	337.0	13.2
China	3.5	0.2	0.0		1.0	0.1*	1.0	0.0*	1.1	0.0
Czechoslovakia	1.7	0.1	0.9	0.1	1.1	0.1	2.0	0.1	2.0	0.1*
France	1.0	0.1	1.0	0.1	1.1	0.1	1.0	0.0	1.0	0.0*
Germany	53.6	2.8	50.9	5.4	61.6	3.6	65.5	2.8	} 50.0	2.0*
Austria	3.9	0.2	2.0	0.2	1.8	0.1	2.1	0.1		
India	1.7	0.1	4.5	0.5	7.3	0.4	6.9	0.3	8.0	0.3*
Japan	75.5	4.0	71.0	7.6	78.0	4.5	87.6	3.7	110.0	4.3*
Mexico	59.0	3.1	34.0	3.6	32.6	2.8	45.8	2.0	34.4	1.4
Norway	2.4	0.1	5.4	0.5	8.4	0.4	8.3	0.4	8.0	0.3*
Peru	54.0	2.8	22.5	2.4	32.8	1.9	35.4	1.5	33.6	1.3
Rhodesia	5.9	0.3	69.0	7.4	144.6	8.4	211.5	9.0	255.0	10.0*
Soviet Union	25.0	1.3	35.0	3.7	83.0	4.8	94.2	4.0	200.0	7.9*
Spain	28.5	1.5	15.6	1.7	10.1	0.6	10.2	0.4	10.0	0.4*
Sweden	4.7	0.2	3.1	0.3	9.5	0.5	9.1	0.4	12.0	0.5*
Union of South Africa	9.3	0.5	9.4	0.1	8.6	0.5	13.3	0.6	18.0	0.7*
United Kingdom	22.0	1.2	13.0	1.4	9.5	0.5	7.5	0.3	5.0	0.5*
United States	998.8	52.6	279.0	29.8	592.6	34.4	820.3	35.0	922.4	36.2
Yugoslavia	20.7	1.1	30.2	3.2	39.4	2.4	39.4	1.7	43.0	1.7
World total ▾	1,904.0		935.0		1,719.5		2,343.2		2,550.0*	

* Estimated.

▾ Several minor producers included in world total not listed in table.

TABLE XXXI

PRODUCTION OF NATURAL GRAPHITE IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Austria	25,296(17.1%)	10,598(15.6%)	21,710(15.0%)	18,157(11.9%)	20,000(9.1%)[a]
Canada	1,325(0.9%)	314(0.5%)	3,700(2.6%)	2,674(1.7%)	300(0.1%)[a]
Ceylon	12,942(8.7%)	6,200(9.1%)	13,731(9.5%)	17,659(11.5%)	24,412(11.1%)
Chosen	24,645(16.7%)	16,581(24.3%)	39,794(27.4%)	43,567(28.5%)	100,000(45.5%)[a]
Czechoslovakia	23,643(16.0%)	922(1.4%)	2,926(2.0%)	5,127(3.3%)	5,000(2.3%)[a]
Germany	21,349(14.4%)	20,796(30.6%)	24,290(16.7%)	23,442(15.3%)	25,000(11.4%)[a]
India	40(0.0%)	5(0.2%)	394(0.3%)	567(0.4%)[a]	500(0.2%)[a]
Italy	7,474(5.0%)	2,943(4.3%)	5,200(3.6%)	5,413(3.5%)	6,000(2.7%)[a]
Japan	308(0.2%)	495(0.7%)	1,576(1.1%)	1,800(1.2%)[a]	2,000(0.9%)[a]
Madagascar	16,049(10.8%)	2,150(3.2%)	7,296(5.0%)	10,628(7.0%)	11,000(5.0%)[a]
Mexico	5,721(3.9%)	2,045(3.0%)	10,253(7.1%)	11,208(7.3%)	13,200(6.0%)
Norway	0	672(1.0%)	3,398(2.3%)	3,743(2.5%)	2,500(1.1%)[a]
Soviet Union	0	3,500(5.1%)[a]	7,000(4.8%)[a]	8,000(5.2%)[a]	9,000(4.1%)[a]
United States	5,859(4.0%)	0	50(0.0%)[a]	50(0.0%)[a]	3,000(1.4%)[a]
World total[b]	148,000	68,100	145,000[a]	153,000[a]	220,000[a]

[a] Estimated. [b] Several minor producers included in world total not listed in table.

TABLE XXXII

PRODUCTION OF IRON ORE DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Algeria	2,196	1.1	67	0.1	1,884	1.1	2,427	1.1	1,500	0.7*
Australia	869	0.4	555	0.8	1,920	1.1	1,901	0.9	2,500	1.2*
Austria	1,891	0.9	307	0.4	1,024	0.6	1,885	0.8	3,000	1.4*
Belgium	156	0.1	93	0.1	191	0.1	265	0.1	150	0.1*
Brazil	30	0.0	30	0.0	111	0.1	210	0.1	255	0.1
Chile	1,812	0.9	173	0.2	1,348	0.8	1,490	0.7	1,750	0.8
China	2,672	1.3	1,253	1.7	1,323	0.8	596	0.3	551	0.3
Cuba	682	0.3	83	0.1	457	0.3	496	0.2	213	0.1
Czechoslovakia	1,808	0.9	602	0.8	1,090	0.6	1,836	0.8	2,000	0.9*
France	50,731	25.2	27,554	37.4	33,302	19.6	37,839	17.1	25,000	11.8*
Germany	6,191	3.1	1,319	1.8	7,340	4.3	9,575	4.3	15,000	7.1*
Hungary	252	0.1	53	0.1	280	0.2	290	0.1	300	0.1*
India	2,467	1.0	1,789	2.4	2,567	1.5	2,883	1.3	3,600	1.7*
Italy	715	0.4	458	0.6	839	0.5	998	0.4	1,000	0.5*
Japan	177	0.1	1,037	1.4	754	0.4	800	0.4*	800	0.4*
Luxembourg	7,571	3.8	3,213	4.4	4,896	2.9	7,766	3.7	7,000	3.3*
Malaya	822	0.4	699	1.0	1,681	1.0	1,687	0.8	1,873	0.9
Mexico	113	0.1	20	0.0	123	0.1	136	0.1	111	0.1
Morocco Spanish	1,061	0.5	171	0.2	1,047	0.9	1,425	0.6	1,500	0.7*
Newfoundland	1,541	0.8	151	0.2	907	0.5	1,635	0.7	1,533	0.7
Philippine Islands	0		0		654	0.4	601	0.3	1,192	0.6
Poland	659	0.3	77	0.1	467	0.3	780	0.4	400	0.2*
Soviet Union	7,849	3.9	12,063	16.4	27,918	16.4	26,000	11.7	30,000	14.1*
Spain	6,547	3.3	1,760	2.4	2,046	1.2	991	0.4	2,900	1.4
Sweden	11,467	5.7	3,299	4.5	11,250	6.6	14,952	6.7	9,000	4.2*
Tunisia	977	0.5	209	0.3	750	0.4	944	0.4	300	0.1*
United Kingdom	13,428	0.7	7,446	10.0	12,905	7.6	14,443	6.5	14,000	6.6*
United States	74,200	37.9	10,005	13.6	49,572	29.2	73,251	33.0	74,879	35.3
World total**	201,187		73,486		170,000		211,000		206,000*	

* Estimated.

** Several minor producers included in world total not listed in table.

TABLE XXXIII

PIG IRON PRIOR TO 1890
(In thousands of tons)

Date	CHIEF PRODUCERS					
	Great Britain	France	Germany	United States	Various	Total
1500	6	12	5	—	37	60
1700	12	22	10	—	60	104
1740	20	26	18	1	92	157
1790	68	40	30	30	110	278
1800	190	60	40	40	130	460
1810	250	85	46	55	180	616
1820	400	140	90	110	270	1,010
1830	680	220	120	180	385	1,585
1840	1,390	350	170	290	480	2,680
1850	2,250	570	402	560	640	4,422
1860	3,830	900	530	820	1,100	7,180
1870	5,960	1,180	1,390	1,670	1,710	11,910
1880	7,750	1,730	2,730	3,840	2,090	18,140
1885	7,420	1,630	3,690	4,050	2,310	19,100
1889	8,250	1,720	4,530	7,600	3,060	25,160

MINOR COUNTRIES

Country	1830	1850	1860	1870	1880	1889
Belgium	35	73	220	520	490	850
Austria	80	140	310	400	470	760
Russia	120	220	290	350	450	600
Sweden	105	130	180	290	400	460
Spain	20	40	50	70	160	230
Various	25	37	50	80	120	160
Total	385	640	1,100	1,710	2,090	3,060

TABLE XXXIV

PRODUCTION OF PIG IRON DURING REPRESENTATIVE YEARS
(In thousands of long tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Austria	450	0.5	94	0.2	248	0.3	389	0.4		
Belgium	3,970	4.1	2,783	7.1	3,207	3.6	3,843	3.7	2,190	2.1*
Czechoslovakia	1,643	1.7	450	1.1	1,140	1.3	1,675	1.6		
France	10,439	10.8	5,549	14.1	6,237	6.9	7,917	7.7	4,550	4.3*
Germany	13,401	13.9	3,933	10.0	15,303	17.1	15,957	15.5	20,600	19.7*
Hungary	350	0.4	66	0.2	306	0.3	362	0.3	350	0.3*
India	1,348	1.4	699	1.8	1,541	1.7	1,598	1.5	2,016	1.9
Italy	678	0.7	461	1.2	816	0.9	970	0.9	876	0.8*
Japan	1,750	1.8	1,542	3.9	2,869	3.2	3,261	3.2	2,946	2.8*
Luxembourg	2,906	3.0	1,959	5.0	1,987	1.3	2,513	2.4	1,050	1.0*
Poland	704	0.7	199	0.5	582	0.6	724	0.7		
Soviet Union	4,018	4.2	6,370	16.2	14,400	16.0	14,520	14.1	15,470	14.8*
Spain	709	0.7	288	0.7	281	0.3	108	0.1	600	0.6*
Sweden	490	0.6	262	0.7	585	0.7	646	0.6	570	0.5*
United Kingdom	7,580	7.9	3,573	9.1	7,686	8.6	8,497	8.3	8,320	7.9*
United States	42,614	44.3	8,781	22.4	31,029	34.6	37,127	36.3	41,800	39.9
World total**	96,263		39,275		89,802		102,848		104,667*	

* Estimated.
** World total includes some minor producers not listed in the table.

Austria, Czechoslovakia, and Poland included under Germany for 1940.

TABLE XXXV

PRODUCTION OF STEEL INGOTS AND CASTINGS DURING REPRESENTATIVE YEARS
(In thousands of long tons)

	1929	%	1932	%	1936	%	1937	%	1940	%
Australia	348	0.3	255	0.5	717	0.6	805	0.6	1,250	0.9*
Austria	630	0.5	205	0.4	418	0.3	650	0.5		
Belgium	4,039	3.4	2,758	5.5	3,105	2.5	3,777	2.8	2,230	1.6*
Canada	1,380	1.2	343	0.7	1,115	0.9	1,403	1.0	2,011	1.4*
Czechoslovakia	2,145	1.8	685	1.4	1,559	1.2	2,315	1.7		
France	9,666	8.2	5,604	11.2	6,562	5.3	7,761	5.7	5,450	3.8*
Germany	16,246	13.7	5,751	11.5	19,158	15.3	19,816	14.6	25,130	17.5*
Hungary	526	0.4	200	0.4	460	0.4	706	0.5	739	0.5*
India	580	0.5	602	1.2	880	0.7	971	0.7	1,365	1.0
Italy	2,189	1.8	1,374	2.7	2,028	1.6	2,087	1.5	2,500	1.7*
Japan	2,100	1.8	2,360	4.7	5,368	4.3	5,719	4.2	6,339	4.4*
Luxembourg	2,702	2.3	1,956	3.9	1,981	1.6	2,510	1.9	1,300	0.9*
Poland	1,377	1.2	551	1.1	1,143	0.9	1,450	1.1		
Soviet Union	4,723	4.0	5,800	11.6	16,300	13.1	17,824	13.2	19,465	15.6*
Spain	929	0.8	455	0.9	471	0.4	99	0.1	750	0.5*
Sweden	694	0.6	537	1.1	1,022	0.8	1,104	0.8	875	0.6*
United Kingdom	9,655	8.2	5,257	10.5	11,698	9.4	12,963	9.6	13,400	9.4*
United States	56,433	47.5	13,681	27.4	48,478	38.7	51,792	38.3	59,806	41.5
World total **	118,282		50,012		124,794		135,317		143,430*	

* Estimated.
** World total includes some minor producers not listed in the table.

Australia and India estimated for 1940.
Austria, Czechoslovakia, and Poland included under Germany for 1940.

TABLE XXXVI

SMELTER PRODUCTION OF LEAD IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Argentina	9,020(0.5%)	3,481(0.3%)	10,700(0.7%)	9,900(0.6%)	15,000(0.8%)*
Australia	180,358(10.1%)	189,347(16.3%)	196,051(13.8%)	232,198(13.8%)	275,000(15.3%)*
Belgium	82,850(4.6%)	64,160(5.5%)	67,000(4.5%)	93,310(5.6%)	55,000(3.1%)*
Burma	81,521(4.6%)	72,345(6.2%)	74,329(5.0%)	77,728(4.6%)	83,000(4.6%)*
Canada	138,095(7.7%)	114,820(10.6%)	164,857(11.1%)	181,162(10.5%)	210,000(11.7%)*
China	2,190(0.1%)	2,728(0.2%)	1,600(0.1%)*	1,500(0.1%)*	1,800(0.1%)
Chosen	333(0.0%)	453(0.0%)	2,738(0.2%)	5,850(0.3%)	6,000(0.3%)*
Czechoslovakia	4,609(0.3%)	4,124(0.4%)	4,126(0.3%)	4,300(0.3%)	a
France	20,358(1.1%)	19,600(1.7%)	15,127(1.0%)	37,168(2.2%)	20,000(1.1%)*
Germany	97,900(5.5%)	95,216(8.2%)	139,000(9.4%)	162,400(9.7%)	200,000(11.1%)*
Austria	6,569(0.4%)	1,986(0.2%)	8,732(0.6%)	10,836(0.6%)	a
Greece	5,361(0.3%)	6,482(0.6%)	4,172(0.3%)	5,890(0.4%)	5,000(0.3%)*
Italy	22,650(1.3%)	31,471(2.7%)	36,307(2.5%)	38,938(2.5%)	35,000(1.9%)*
Japan	3,374(0.6%)	6,415(0.6%)	8,883(0.6%)	10,200(0.6%)	15,000(0.8%)*
Mexico	239,952(10.3%)	132,890(11.4%)	214,376(14.5%)	214,653(12.8%)	195,071(10.9%)
Peru	19,448(1.1%)	327(0.0%)	8,899(0.6%)	19,053(1.1%)	37,072(2.1%)
Poland	35,789(2.0%)	11,902(1.0%)	15,021(1.0%)	17,587(1.0%)	a
Rumania	565(0.0%)	1,938(0.0%)	4,783(0.3%)	6,725(0.4%)	5,500(0.3%)*
South-West Africa	2,802(0.2%)	1,044(0.1%)	0	1,355(0.1%)	690(0.0%)
Soviet Union	6,200(0.3%)	18,717(1.6%)	50,800(3.4%)	55,000(3.3%)*	75,000(4.2%)*
Spain	142,753(18.0%)	105,370(9.1%)	46,600(3.2%)	30,000(1.8%)	40,000(2.3%)*
Tunisia	18,850(1.1%)	14,082(1.2%)	21,497(1.5%)	24,758(1.5%)	24,000(1.4%)*
United Kingdom	10,839(0.6%)	7,100(0.6%)	13,800(0.9%)	10,313(0.6%)	10,000(0.6%)*
United States	636,997(36.7%)	245,541(21.2%)	362,055(24.5%)	423,232(25.2%)	468,675(26.0%)
Yugoslavia	9,471(0.5%)	8,321(0.7%)	5,804(0.4%)	4,038(0.2%)	14,000(0.8%)*
World total**	1,788,000	1,160,000	1,478,000	1,679,000	1,800,000*

* Estimated. a Included under Germany. ** Several minor producers included in world total not listed in table.

TABLE XXXVII

PRODUCTION OF MANGANESE DURING REPRESENTATIVE YEARS
(In thousands of metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Brazil	316.2	9.2	20.3	1.5	156.2	3.0	253.7	4.2	217.3	3.6
Bulgaria	0.0		0.0		1.5	0.0	3.0	0.0	1.5	0.0*
Chile	3.1	0.1	0.5	0.0	5.2	0.1	13.0	0.2	19.5	0.3
China	41.9	1.2	20.7	1.6	23.8	0.4	51.4	0.9	0.0	0.0
Cuba	1.0	0.0	9.8	0.8	48.5	0.9	131.3	2.1	119.9	2.0
Egypt	191.5	5.5	0.3	0.0	134.1	2.6	186.3	3.1	150.0	2.5*
French Morocco	13.1	0.4	4.0	0.3	39.4	0.8	76.5	1.3	60.0	1.0*
Gold Coast	465.3	13.5	51.5	3.9	417.6	8.1	535.5	8.9	600.0	10.0*
Greece	1.6	0.0	0.7	0.1	1.7	0.0	7.0	0.1	12.0	0.2*
Hungary	19.0	0.6	1.5	0.1	27.2	0.5	25.1	0.4	27.0	0.4*
India	1,015.3	29.4	219.6	16.8	829.2	16.0	1,072.5	17.8	1,200.0	20.0*
Italy	9.9	0.3	0.4	0.0	24.1	0.5	33.5	0.6	60.0	1.0*
Japan	18.4	0.5	20.9	1.6	67.8	1.3	70.0	1.2*	70.0	1.1*
Malaya	0.0		0.0		37.4	0.7	33.3	0.6	32.0	0.5*
Netherlands Indies	20.9	0.6	8.3	0.6	8.6	0.2	11.1	0.2	12.0	0.2*
Philippine Islands	0.0		0.0		0.3	0.0	12.2	0.2	58.0	1.0
Rumania	35.0	1.0	5.1	0.4	33.9	0.7	50.7	0.8	60.0	1.0*
Soviet Union	1,183.9	34.4	915.3	70.0	3,002.0	58.0	2,752.0	45.6	3,000.0	50.0*
Sweden	13.7	0.4	3.0	0.2	5.9	0.1	5.8	0.1	6.0	0.1*
Turkey	0.2	0.0	2.8	0.2	4.6	0.1	0.5	0.0	3.0	0.0*
Union of South Africa	9.3	0.3	0.0		258.2	5.0	631.2	10.9	412.1	6.9
United States	61.3	1.8	18.1	1.4	32.6	0.6	40.9	0.7	40.8	0.7
Yugoslavia	3.1	0.1	0.2	0.0	2.7	0.1	4.4	0.7	6.0	0.1*
World total **	3,452.0		1,310.0		5,177.0		6,039.0*		6,000.0*	

* Estimated.

** Several minor producers included in world total not listed in table.

TABLE XXXVIII

PRODUCTION OF MERCURY IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Algeria	4.2	0.1	40.8	1.5	3.5	0.1	4.8	0.1	5.0	0.1*
Australia	0.0		0.9	0.0	2.7	0.1	0.3	0.0	?	
Bolivia	1.7	0.0	17.4	0.7	7.7	0.2	0.6	0.0	?	
Canada	0.0		0.0		0.0		0.0		350.0	4.6*
China	20.0	0.4	20.0	0.8	84.8	2.0	59.8	1.3	215.8	2.8
Czechoslovakia	65.4	1.2	45.0	1.7	64.7	1.5	94.8	2.3	100.0	1.3*
Germany	0.0		0.0		37.7	0.9	61.1	1.3	60.0	0.8*
Italy	1,998.3	35.6	1,016.3	38.4	1,473.1	34.5	2,308.4	50.4	2,100.0	27.6*
Japan	1.4	0.0	2.4	0.1	14.8	0.3	20.0	0.4	20.0	0.3*
Mexico	82.6	1.5	253.4	9.5	183.0	4.3	170.2	3.7	401.7	5.3
Soviet Union	130.0	2.3	?		300.0	7.0*	300.0	6.5*	300.0	3.9*
Spain	2,476.3	43.7	815.5	30.8	1,497.0	35.0	977.5	21.3	2,700.0	35.5*
Turkey	8.1	0.1	0.0		28.1	0.7	16.7	0.4	15.0	0.2*
United States	816.4	14.6	435.1	16.4	571.2	13.4	569.1	12.4	1,302.3	17.1
World total**	5,608.8		2,649.2*		4,270.7*		4,589.6*		7,600.0*	

* Estimated.
** World total includes some minor producers not listed in the table.

TABLE XXXIX

PRODUCTION OF MICA IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Argentina	119	0.4	55	0.3	210	0.5	225	0.4	300	0.6[e]
Australia	27	0.1	30	0.2	21	0.1	85	0.2	32	0.1
Brazil	45	0.2	42	0.2	237	0.6	330	0.6	1,117	2.5
Canada	3,677	12.6	280	1.6	726	1.8	857	1.7	1,000	2.1[e]
Chosen	26	0.1	20	0.1	70	0.2	70	0.1	70	0.1[e]
India	5,897	20.3	2,389	14.0	9,026	22.8	15,106	29.2	10,000	21.3[e]
Italy	0		9	0.0	12	0.0	24	0.0	125	0.3[e]
Madagascar	380	1.3	140	0.8	410	1.0	583	1.1	700	1.5[e]
Norway	59	0.2	103	0.6	43	0.1	42	0.1	50	0.1[e]
Rhodesia	175	0.6	13	0.1	12	0.0	21	0.0	10	0.0[e]
Rumania	0		0		67	0.2	27	0.1	25	0.1[e]
Soviet Union	?		7,075	41.4	8,500	21.4[e]	9,000	17.4[e]	11,000	23.4[e]
Sweden	66	0.2	61	0.4	125	0.3	68	0.1	125	0.3[e]
Tanganyika Territory	29	0.1	12	0.1	44	0.1	71	0.1	40	0.1[e]
Union of South Africa	1,464	5.0	250	1.5	495	1.2	1,740	3.4	1,252	2.7
United States	6,596	22.8	6,540	38.4	19,609	49.4	23,626	45.7	21,046	44.8
World total[w]	29,000		17,049		39,650[e]		51,875[e]		47,000[e]	

[e] Estimated.
[w] Several minor producers included in world total not listed in table.

TABLE XL

PRODUCTION OF MOLYBDENUM ORES AND CONCENTRATES
(In metric tons of contained molybdenum)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Australia	1	0.0	3	0.2	9	0.1	10	0.1	?	
Mexico	0		5	0.4	499	5.6	522	3.6	313	1.9
Morocco	0		0		107	1.2	97	0.7	100	0.6*
Norway	154	7.7	168	13.1	422	4.7	360	2.5	400	2.4*
Peru	0		0		12	0.1	61	0.4	204	1.2
United States	1,828	91.1	1,111	86.3	7,796	87.3	13,345	92.1	15,565	91.6
Other Countries	22	1.1	0		90	1.0	93	0.6	50	0.3*
World Total	2,005		1,287		8,935		14,488		16,632*	

* Estimated.

TABLE XLI

PRODUCTION OF NICKEL (IN ORE) DURING REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Brazil	0		0		478	0.5	104	0.1	?	
Burma	838	1.5	945	4.3	1,312	1.4	1,233	1.0	1,200	0.9[e]
Canada	49,664	87.7	13,756	63.0	76,992	82.4	102,015	84.9	100,000	78.7[e]
Germany	0		0		660	0.7	890	0.7	?	
Greece	256	0.5	953	4.4	1,255	1.3	957	0.8	800	0.6[e]
Morocco	0		0		85	0.1	132	0.1	150	0.1[e]
Netherlands Indies	0		0		0		0		750	0.6[e]
New Caledonia	4,338	7.6	5,000	22.9	9,200	9.8	11,600	9.6	17,500	13.8
Norway	435	0.8	975	4.5	1,270	1.3	877	0.7	750	0.6[e]
Southern Rhodesia	0		0		14	0.0	4	0.0	500	0.4[e]
Soviet Union	0		0		2,000	2.1	2,000	1.7	3,500	2.8[e]
Union of South Africa	0		0		0		0		400	0.3[e]
United States	306	0.5	177	0.8	97	0.1	199	0.2	503	0.4
World total[w]	56,650		21,807		93,400		120,100		127,000[e]	

[e] Estimated.
[w] Several minor producers included in world total not listed in table.

TABLE XLII

PRODUCTION OF SODIUM NITRATE IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Chile	3,237,594	693,878	1,268,500	1,443,000	1,488,000

TABLE XLIII

WORLD PRODUCTION OF NITROGEN IN REPRESENTATIVE YEARS
(In metric tons)

Source	Years								
	1929	%	1932	%	1936	%	1937	%	1940
Chile nitrate	490,000	23.2	170,000	10.7	218,000	8.9	238,000	8.7	
Manufactured nitrogen	1,623,000	76.8	1,415,000	89.3	2,223,000	91.1	2,492,000	91.3	
World total	2,113,000		1,585,000		2,441,000		2,730,000		

TABLE XLIV

PRODUCTION OF PETROLEUM DURING REPRESENTATIVE YEARS
(In millions of barrels of 42 U.S. gallons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Arabia							0.1	0.0	5.6	0.3
Argentina	9.4	0.6	13.1	1.0	15.4	0.9	16.3	0.8	20.3	0.9
Borneo	5.3	0.4	3.8	0.3	5.2	0.3	6.0	0.3	7.0	0.3
Burma [a]					7.6	0.4	7.8	0.4	8.0	0.4
Canada	1.1	0.1	1.0	0.1	1.5	0.1	3.0	0.1	9.0	0.4
Columbia	20.4	3.6	16.4	1.3	18.7	1.0	20.3	1.0	26.0	1.2
Egypt	1.9	0.1	1.9	0.1	1.3	0.1	1.2	0.1	5.1	0.2
Germany	.7	0.0	1.6	0.1	3.1	0.2	3.2	0.2	4.5	0.2
India [b]	8.7	0.6	8.8	0.7	2.1	0.1	2.5	0.1	2.2	0.1
Iran	42.1	2.8	49.5	3.8	62.7	3.5	77.9	3.8	79.3	3.7
Iraq	0.8	0.1	0.8	0.1	30.4	1.7	31.8	1.6	25.7	1.2
Japan	2.0	0.1	1.6	0.1	2.4	0.1	2.5	0.1	2.6	0.1
Mexico	44.7	3.0	32.8	2.5	41.0	2.3	46.9	2.3	44.1	2.0
Netherlands East Indies	38.1	2.6	39.0	3.0	50.0	2.8	56.7	2.8	60.8	2.8
Rumania	34.7	2.3	53.8	4.1	64.2	3.6	52.7	2.6	43.8	2.0
Soviet Union	100.6	6.8	157.0	12.0	202.3	11.2	198.8	9.7	215.6	10.0
Trinidad	8.7	0.6	10.1	0.8	13.2	0.7	15.5	0.8	20.2	0.9
United States	1,007.3	67.8	785.1	59.2	1,089.7	60.3	1,279.2	62.6	1,351.8	62.8
Venezuela	137.5	9.2	116.5	8.9	154.8	8.5	186.8	9.1	186.8	8.6
World total [c]	1,485.9		1,309.7		1,804.9		2,041.7		2,154.2	

[a] Included under India 1929 and 1932.
[b] Includes Burma 1929 and 1932.
[c] Several minor producers included in world total not listed in table.

TABLE XLV

PRODUCTION OF PHOSPHATE ROCK IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Algeria	747,035	7.1	569,279	8.5	530,998	5.1	631,148	5.3	350,000	3.4[e]
Angaur Island	65,494	0.6	65,609	1.0	89,226	0.9	90,652	0.8	150,000	1.5[e]
Belgium	40,330	0.4	25,810	0.4	16,090	0.2	27,296	0.2	27,000	0.3[e]
Christmas Island[a]	119,756	1.1	85,548	1.3	157,564	1.5	154,378	1.3	230,000	2.2[e]
Curacao[b]	103,289	1.0	65,407	1.0	78,131	0.7	101,837	0.8	5,896	0.1
Egypt	215,311	2.0	349,780	5.2	531,031	5.1	517,002	4.3	75,000	0.7[e]
Estonia	8,352	0.1	1,133	0.0	11,408	0.1	10,112	0.1	5,000	0.0[e]
France	179,620	1.7	82,700	1.2	55,000	0.5	103,600	0.9	20,000	0.2[e]
Indochina	18,772	0.2	373	0.0	10,336	0.1	20,252	0.2	36,000	0.3[e]
Japan	14,573	0.1	18,707	0.3	113,102	1.1	128,314	1.1	235,000	2.2[e]
Makatea Island	242,990	2.3	120,650	1.8	122,936	1.2	166,726	1.4	165,000	1.6[e]
Morocco (French)	1,608,249	15.2	987,317	14.6	1,257,796	12.0	1,501,767	12.5	700,000	6.8[e]
Nauru[c]	585,844	5.6	438,466	6.5	965,349	9.3	1,024,168	8.5	1,267,014	12.3
Netherlands Indies	3,172	0.0	2,724	0.0	12,072	0.1	26,167	0.2	20,000	0.2[e]
Poland	39,294	0.4	0		12,497	0.1	15,000	0.1	12,000	0.1[e]
Seychelles Islands	12,789	0.1	14,213	0.2	23,942	0.2	9,594	0.1	25,000	0.2[e]
Soviet Union	81,000	0.8	156,500	2.3	920,000	8.9	1,598,000	13.3	1,700,000	16.5[e]
Spain	7,626	0.1	9,980	0.1	8,000	0.1	14,497	0.1	65,000	0.6[e]
Tunisia	2,511,000	23.8	1,678,000	25.0	1,488,000	14.3	1,771,439	14.8	950,000	9.2[e]
United States	3,821,217	36.2	1,734,300	25.8	3,405,654	32.7	4,019,686	33.6	4,066,943	39.5
World total	10,526,231		6,714,496		10,413,000[e]		11,969,000[e]		10,300,000[e]	

[a] Straits Settlements. [b] Netherlands West Indies. [c] Including Ocean Island. [e] Estimated.

TABLE XLVI

PRODUCTION OF POTASSIUM MINERALS IN TERMS OF POTASSIUM OXIDE CONTENT IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Australia	3	0.0	0		82	0.0	?		?	
China	0		5	0.0	23	0.0	10	0.0	1,100	0.0[e]
Chosen	120	0.0	165	0.0	1,150	0.0	1,500	0.0	?	[e]
Eritrea	350	0.0	0		80	0.0	?		?	
France	492,097	20.2	326,500	23.4	368,880	14.5	489,801	15.7	500,000	15.4[e]
Germany	1,787,775	73.4	871,354	62.6	1,622,650	63.4	1,968,416	63.2	1,900,000	58.6[e]
India	2,300	0.1	4,400	0.3	4,200	0.2	4,300	0.1	4,000	0.1[e]
Italy	2,700	0.1[e]	3,604	0.3	477	0.0	420	0.0	?	
Palestine	0		5,100	0.4	11,727	0.5	18,234	0.6	25,000	0.8[e]
Poland	63,735	2.6	57,044	4.1	82,935	3.3	99,940	3.2	100,000	3.1[e]
Soviet Union	950	0.0[e]	10,700	0.8	225,000	8.8	266,000	8.5	350,000	10.8[e]
Spain	24,600	1.0[e]	55,000	3.9	0		0		?	
United States	55,873	2.3	56,236	4.0	224,382	8.8	258,090	8.3	344,437	10.6
World total[w]	2,435,000[e]		1,392,000[e]		2,542,000[e]		3,107,000[e]		3,225,000[e]	

[e] Estimated. [w] Several minor producers included in world total not listed in table.

TABLE XLVII

PRODUCTION OF SULPHUR IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Bolivia	?		?		950	0.0	1,739	0.0	4,130	0.1
Canada [b]	0		0		?		12,277	0.3	100,000	2.7[e]
Chile	16,300	0.5	11,959	0.9	25,935	1.0	17,035	0.5	29,462	0.8
Italy	323,837	10.9	349,978	25.0	327,570	12.1	343,528	9.6	350,000	9.5[e]
Japan	65,464	2.2	84,530	6.5	175,314	6.5	185,000	5.1[e]	150,000	4.1[e]
Netherlands Indies	?		7,699	0.5	11,493	0.4	12,268	0.3	12,000	0.3[e]
Norway [b]	?		50,000	3.6[e]	65,000	2.4[e]	100,000	2.8[e]	75,000	2.0[e]
Peru	0		0		1,723	0.1	1,576	0.0	626	0.0
Spain	11,903	0.4	8,243	0.6	?		?		30,000	0.8[e]
Sweden	0		0		19,616	0.7	18,432	0.5	20,000	0.5[e]
Turkey	0		0		3,189	0.1	2,265	0.1	2,500	0.1[e]
United States	2,400,305	81.1	904,731	64.5	2,048,700	75.9	2,785,979	77.4	2,775,938	74.8
World total [w]	2,957,000[e]		1,400,000[e]		2,700,000[e]		3,600,000[e]		3,700,000[e]	

[e] Estimated. [b] By-product sulphur. [w] Several minor producers included in world total not listed in table.

TABLE XLVIII

PRODUCTION OF TIN (IN ORE) DURING REPRESENTATIVE YEARS
(In long tons of 2,240 pounds)

Restricted Production

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Belgian Congo	971	0.5[a]	689	7.3[a]	6,301	3.5	8,084	3.9	7,600	3.3[e]
Bolivia	46,343	23.5[a]	20,589	21.8	24,052	13.5	25,128	12.0	37,923	16.4
Indochina	829	0.4[a]	1,010	1.1[a]	1,381	0.8	1,577	0.8	1,560	0.7
Malaya	69,368	35.9[a]	28,377	30.1	66,717	37.2	77,264	37.1	85,384	36.8
Netherlands Indies	35,236	18.2[a]	16,789	17.8	30,728	17.1	39,133	18.8	44,447	19.2
Nigeria	10,734	5.6[a]	4,320	4.6	9,648	5.4	10,782	5.1	12,012	5.2
Thailand (Siam)	10,517	5.5[a]	9,276	9.9	12,633	7.1	15,786	7.6	17,447	7.5

Unrestricted Production

Argentina	?		?		940	0.5	1,423	0.7	1,600	0.7[e]
Australia	2,239	1.2	2,138	2.3	3,027	1.7	3,256	1.6	3,300	1.4[e]
Burma	2,649	1.4	3,168	3.4	4,546	2.5	4,636	2.2	5,500	2.4[e]
China	6,778	3.5	2,009	2.2	11,082	6.2	12,871	6.2	6,349	2.7
Germany	?		?		50	0.0	100	0.0[e]	300	0.1[e]
Italy	0		?		36	0.0	131	0.1	250	0.1[e]
Japan	1,092	0.6	1,557	1.7[e]	2,382	1.3	2,175	1.0	2,000	0.9[e]
Mexico	?		751	0.8	368	0.2	373	0.2	300	0.1[e]
Portugal	500	0.3[e]	550	0.6	858	0.5[b]	1,095	0.6	2,000	0.9[e]
Union of South Africa	1,218	0.6	541	0.6	634	0.4	537	0.3	500	0.2[e]
United Kingdom	3,271	1.7	1,337	1.4	2,099	1.2[b]	1,987	1.0	1,800	0.8[e]
United States	35	0.0	1	0.0	101	0.1	168	0.1	44	0.0
World total[w]	193,000[e]		94,000[e]		179,000[e]		208,100[e]		231,700[e]	

[a] Production unrestricted during this year. [b] Production restricted in 1936. [e] Estimated. [w] Several minor producers included in total not listed in table.

TABLE XLIX

PRODUCTION OF TUNGSTEN ORE DURING REPRESENTATIVE YEARS
(In metric tons of concentrates containing 60 per cent tungsten trioxide [WO_3])

Country	Years				
	1929	1932	1936	1937	1940
North America					
Mexico	11(0.1%)	0	57(0.3%)	33(0.1%)	112(0.3%)
United States	753(4.8%)	359(5.3%)	2,370(9.5%)	3,175(8.4%)	4,825(11.8%)
South America					
Argentina	63(0.4%)	6(0.1%)	702(2.8%)	866(2.3%)	1,560(3.8%)*
Bolivia	1,630(10.3%)	686(10.1%)	1,741(7.0%)	1,802(4.8%)	4,183(10.2%)
Peru	0	0	92(0.4%)	30(0.08%)	290(0.7%)
Europe					
Great Britain (Cornwall)	27(0.2%)	2(0.0%)	221(0.9%)	148(0.4%)	250(0.6%)*
Portugal	358(2.3%)	272(4.0%)	1,414(5.7%)	2,069(5.5%)	4,858(11.8%)
Spain	257(1.6%)	43(0.6%)	?	?	500(1.2%)*
Sweden	0	0	62(0.2%)	127(0.3%)	?
Asia					
Burma	1,484(9.4%)	2,226(32.7%)	5,382(21.6%)	5,924(15.7%)	9,000(22.0%)*
China	9,978(63.0%)	2,249(32.8%)	7,638(30.7%)	17,895(47.3%)	11,580(28.2%)
Chosen	15(0.1%)	62(0.9%)	1,849(7.4%)	2,058(5.4%)	2,000(4.9%)*
Indochina	198(1.3%)	247(3.6%)	503(2.0%)	648(1.7%)	392(1.0%)
Japan	61(0.4%)	22(0.3%)	61(0.2%)	42(0.1%)	50(0.1%)*
Malaya	513(3.3%)	553(8.1%)	2,037(8.2%)	1,356(3.6%)	535(1.3%)
Thailand	62(0.4%)	0	82(0.3%)	221(0.6%)	200(0.5%)*
Africa					
Nigeria	0	0	11(0.0%)	9(0.0%)	250(0.6%)*
Southern Rhodesia	28(0.2%)	14(0.2%)	88(0.4%)	275(0.7%)	380(0.9%)
Union of South Africa	0	0	30(0.1%)	40(0.1%)	105(0.3%)
Oceania					
Australia	218(1.6%)	50(0.7%)	426(1.7%)	866(2.3%)	1,100(2.7%)*
World Total**	15,800	6,800	24,867	37,840	41,000*

* Estimated.

** Several minor producers included in world total not listed in table.

TABLE L

PRODUCTION OF VANADIUM (IN ORE) DURING REPRESENTATIVE YEARS
(In metric tons)

Country	Years									
	1929	%	1932	%	1936	%	1937	%	1940	%
Mexico	0		0		0		45	2.3	57	1.8
Northern Rhodesia	60	3.3	307	35.8	204	20.9	235	12.1	400	13.0[e]
Peru	902	49.5[e]	0		161	16.5	583[e]	30.0	1,254	40.6
South West Africa	310	17.0	305	35.6	547	56.1	591	30.3	428	13.8
United States	550	30.2	245	28.6	63	6.5	493	25.3	948	30.7
Total	1,822		857		975		1,947		3,087	

[e] Estimated.

TABLE LI

SMELTER PRODUCTION OF ZINC IN REPRESENTATIVE YEARS
(In metric tons)

Country	Years				
	1929	1932	1936	1937	1940
Australia	52,705(3.6%)	54,054(6.9%)	71,641(5.0%)	70,869(4.3%)	85,000(4.9%)*
Belgium	197,900(13.6%)	96,330(12.3%)	201,686(13.8%)	225,580(13.8%)	65,000(3.8%)*
Canada	78,061(5.4%)	78,146(10.0%)	137,078(9.4%)	143,826(8.9%)	180,000(10.4%)*
Czechoslovakia	10,675(0.7%)	6,031(0.8%)	7,670(0.5%)	7,336(0.5%)	[a]
France	87,330(6.1%)	45,700(5.9%)	51,694(3.5%)	60,427(3.7%)	35,000(2.0%)*
Germany	102,000(7.0%)	41,979(5.4%)	133,427(9.1%)	163,814(10.7%)	225,000(13.0%)*
Indochina	3,808(0.5%)	2,280(0.3%)	4,112(0.3%)	4,204(0.3%)	?
Italy	15,804(1.1%)	17,984(2.3%)	27,025(1.8%)	37,982(2.3%)	40,000(2.3%)*
Japan	22,098(1.5%)	27,043(3.5%)	39,066(2.7%)	45,500(2.8%)	60,000(3.4%)*
Mexico	15,099(1.1%)	30,349(3.9%)	31,913(2.2%)	36,587(2.3%)	40,000(2.3%)*
Netherlands	25,712(1.8%)	15,624(2.0%)	15,428(1.0%)	24,645(1.6%)	6,000(0.5%)*
Norway	5,516(0.4%)	39,373(5.0%)	45,028(3.2%)	41,276(2.5%)	20,000(1.2%)*
Poland	169,029(11.8%)	84,953(10.9%)	92,580(6.3%)	107,174(6.6%)	120,000(6.9%)*
Rhodesia	12,316(0.8%)	0	21,063(1.4%)	14,256(0.9%)	15,000(0.8%)*
Soviet Union	3,437(0.2%)	14,116(1.8%)	65,000(4.4%)*	65,000(4.0%)*	85,000(4.9%)*
Spain	11,825(0.8%)	9,505(1.2%)	7,803(0.5%)	5,279(0.3%)	12,000(0.7%)*
United Kingdom	59,234(4.1%)	27,300(3.5%)	61,768(4.2%)	63,138(3.9%)	60,000(3.4%)*
United States	567,393(39.1%)	187,921(24.0%)	446,452(30.5%)	505,212(31.7%)	657,000(37.9%)*
Yugoslavia	6,291(0.4%)	2,157(0.3%)	3,599(0.2%)	4,259(0.3%)	?
World total [c]	1,451,000	781,000	1,464,000	1,626,000	1,732,000*

* Estimated. [a] Included with Germany. [c] Several minor producers included in world total not listed in table.

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